NASW-410-30-13-10

DOCUMENTATION

OF

SATURN PROGRAM RF AND TELEMETRY CHECKOUT PROCEDURES

FOR THE

ELECTRONIC ENGINEERING MEASURING AND TRACKING OFFICE

AT THE

LAUNCH OPERATIONS CENTER

6 FEBRUARY 1963

CONTRACT NASw-410

LOC TASK 3

APOLLO SUPPORT DEPARTMENT
GENERAL ELECTRIC COMPANY
DAYTONA BEACH, FLORIDA

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SECTION 1

INTRODUCTION

GENERAL

At the request of NASA, Launch Operations Center (LOC), the General Electric Company has undertaken a four-man-month study of telemetry and RF checkout philosophy and procedures. The study encompassed a documentation of past and present techniques, as well as future NASA planning for the later C-1 and C-5 flights. Pertinent NASA and General Electric documents have been reviewed and discussions have been held with NASA personnel at the Launch Operations Center and Marshall Space Flight Center (MSFC). Excerpts from these documents and information obtained from the discussions have been incorporated into this report in an attempt to present, in a single document, a discussion of methods and techniques of RF and telemetry equipment checkout.

This represents the final report satisfying the requirements of LOC Task No. 3 of the Phase I Study Contract.

RECOMMENDATIONS

It is recommended that this document be periodically reviewed by NASA in order that it may be updated to reflect the current methods and procedures as these change with time.

It is also recommended that a further study program be initiated to analyze the requirements and develop the checkout concepts and procedures for the later C-1 and C-5 vehicle RF and telemetry systems. Personnel assigned to this study should have cognizance of the current operations but should be free to devote full effort to this advanced planning.

SECTION 2

NASA ORGANIZATION

This study is being performed at the request of the Instrumentation Planning Office of LOC. All of the RF and telemetry checkout responsibility lies with the RF and Telemetry Group, with the exception of the UDOP transponder, which lies with the Tracking System Group.

The RF and Telemetry Group is divided into three sections: the Telemetry Field Section, the Telemetry Ground Section, and the RF Section.

The Telemetry Field Section is responsible for the checkout and testing of the airborne portion of the telemetry system. In order to accomplish this, the section operates a ground checkout system at the launch complex. This group has primary responsibility for checkout of the telemetry packages.

The Telemetry Ground Section has the responsibility for the operation of the primary telemetry ground station located in Hangar D. It is at this location that the telemetry information is received and recorded during a launch operation. It is from this location that the telemetry signals are fed to the computer for real-time processing.

The RF Section has the responsibility for the checkout of all on-board RF systems including Azusa, C-Band Beacon, Command Receiver, MISTRAM, Radar Altimeter, Digital Path Correction System, TV systems and Digital Range Safety Command System. As previously mentioned, the UDOP transponder responsibility lies with the Tracking Systems Group.

SECTION 3

CHECKOUT PHILOSOPHY AT MARSHALL SPACE FLIGHT CENTER

In order to determine the checkout requirements at the Launch Operations Center (LOC), it is necessary to know the details of checkout procedures which have been accomplished prior to arrival of the vehicle at the launch site.

Checkout of the S-I Stage at Marshall Space Flight Center (MSFC) is intended to be as complete and comprehensive as possible in order to minimize the testing time at the launch site. Time is minimized not only by the reduced need for exhaustive examination, but also by the reduced need for design modifications.

To this end, MSFC has implemented a checkout plan which begins with thorough bench checks of all components, progresses through checkout, subsystem by subsystem, and culminates in the over-all system tests.

Many components, essentially R&D items, are functionally bench checked twice before assembly for subsystem tests. Each is first checked by the MSFC division that manufactured it, or received it, as in the case of vendor-supplied components. All calibration and timing tests are performed during these comprehensive checks. Test reports are written for each component tested and copies are forwarded, along with the component(s), to subsequent test areas. This procedure establishes a checkout history for determining trends. These components are sent to the Quality Assurance Division (QAD) where second bench checks are performed. However, operational mechanical components and some electrical components come directly to QAD, where they are bench checked for acceptance.

These tests are independent of any performed earlier, in that different people are writing the test procedures and conducting the tests. Thus, there is overlap in acceptance testing, but from independent viewpoints. No repair is performed at QAD. If a given component is not considered acceptable, it is returned to the division that supplied it. The procedure results in a very stringent configuration control. Parameters and operating characteristics measured in these tests are logged, along with previous test results. This is done each time a final measurement is made, so that trends are immediately obvious farther along in the checkout process. Many electrical components are flown as passengers prior to their use as in-line equipment. As such, a component performs a redundant function, but measurements are made to determine its suitability to meet the required performance specifications. If the performance is satisfactory, it becomes prime equipment and replaces the component which has previously supplied this particular function.

Most mechanical components are subjected to "qualification bench testing," in the course of which they are tested in simulated flight environments and proven without being flown as passengers.

After the thorough component testing is completed, the components are assembled into subsystems. Before they are installed in the vehicle, the vehicle's electrical cables undergo a complete continuity check. This minimizes the possibility of damage to equipment due to faulty wiring of electrical components. Each subsystem is individually tested in the vehicle, so that its compatibility is confirmed without the confusion of possible interaction with other systems. These tests reduce the operational difficulties in over-all system tests.

System tests are conducted in three phases; pre-static, static, and post-static. The aforementioned subsystem tests are also performed on a pre-static and post-static basis. The pre-static over-all test verifies the readiness of the vehicle for static firing.

The static firing verfies the operation of the propulsion system and provides, as well, environmental data on the vehicle's structures and subsystems. In addition, certain functions which must be simulated in other system tests can be checked. Among these are engine combustion, fuel and Lox tank pressurizing valve pressure switches and main hydraulic pumps for the control system actuators. Test procedures for the static firings are coordinated with the designers, QAD test engineers, and launch operations personnel. This assures that comprehensive data are obtained.

After the vehicle has been static-fired, it is returned to the assembly area to repair damage resulting from the firing and to design changes found necessary as a result of data obtained during the firing. From here it is sent to the QAD for final acceptance testing.

Post-static is almost identical to pre-static testing. Thus, any permanent changes resulting from the firing are immediately obvious from direct comparison of pre- and post-static results.

Post-static electrical system testing follows a more thorough build-up than does pre-static electrical system testing. This is because all systems are utilized for launching, whereas pre-static testing must verify only those systems which are necessary to accomplish the static firing test. The simulated flight test is designed to check out all systems in as near a flight configuration as possible, using a near actual launch countdown and simulated flight sequence. Substitution and simulation are sparingly used, mostly in the interest of safety. For example, engine combustion pressures are simulated. Thus, the flight-tested hardware is the hardware which will fly.

The QAD which performs final acceptance testing is organizationally independent of the designers and manufacturers as well as the launch crew. This means the hardware gets checked out from, essentially, three independent viewpoints. This results in redundancy, but a thorough checkout results.

The GSE used for prelaunch and launch operations is the same equipment used for final acceptance testing and static testing. Thus, not only is a thoroughly checked vehicle delivered to the launch site, but its compatibility with the GSE is assured. This results in prelaunch activities with sharply curtailed operational difficulties in the vehicle/GSE interface. The GSE and facilities are always checked out with a vehicle simulator prior to mating with the vehicle. This presents a problem in an R&D program because the vehicle, GSE, and simulator must be updated simultaneously. However, this again pays off in a sharp reduction of operational difficulties in testing.

Test data are fed back by keeping continuing records of all final measurements in each test area. These records are included in a final test report, which is sent to cognizant subsystem personnel for evaluation. There is also a close interrelationship between personnel in different checkout organizations and the designers. The design engineers establish test specifications, while the test engineers review these specifications and establish test procedures. In case of trouble, the design engineers are called in and the feedback is instantaneous.

SECTION 4

EQUIPMENT CHECKOUT AT THE LAUNCH OPERATIONS CENTER

TELEMETRY

TECHNICAL DESCRIPTION

Telemetry for SA-1 and SA-2 consisted of eight RF links with a growth to ten links for SA-3 and SA-4 and twelve links for SA-5. Ultimately, for C-5, as many as 26 links may be utilized. Multiplexing includes SS-FM and PCM-FM, as well as PAM/FM/FM. The telemetry system for SA-1 is shown in Figure 4-1, for SA-2 in Figure 4-2, and for SA-3 and SA-4 in Figure 4-3. A breakdown of the measurements for these vehicles is shown in Figure 4-4. This is a preliminary estimate and may be revised. No breakdown is available for SA-5 at this time. However, it is expected that 1000 to 1200 measurements will be made with 12 links: two FM-FM, three PDM-FM-FM, four PAM-FM-FM, two SS-FM, and one PCM/SS-FM. The functional characteristics of the various links used are described below.

Description of Vehicle Telemetry System

As seen from Figure 4-3, the telemetry system consists of 10 telemetry links, with each link transmitting many channels of information. The functional characteristics of the various links used are described in the following paragraphs.

FM/FM

The FM/FM telemetry link is of the frequency division multiplex type, where the electrical signals derived from the transducers modulate the frequencies of the subcarrier oscillators which, in turn, frequency modulate an RF carrier. The standard configuration has 18 subcarrier oscillator channels modulating the RF carrier, with the subcarrier oscillator frequencies ranging from 0.4 kc to 70 kc. The bandwidth varies from six cycles for the 400-cycle channel to 1050 cycles for the 70-kc channel, with the standard ± 7.5-percent frequency deviation and deviation ratio of five. The 400-cycle channel is not used with the Saturn telemetry due to the presence of other 400-cycle signals which would cause interference.

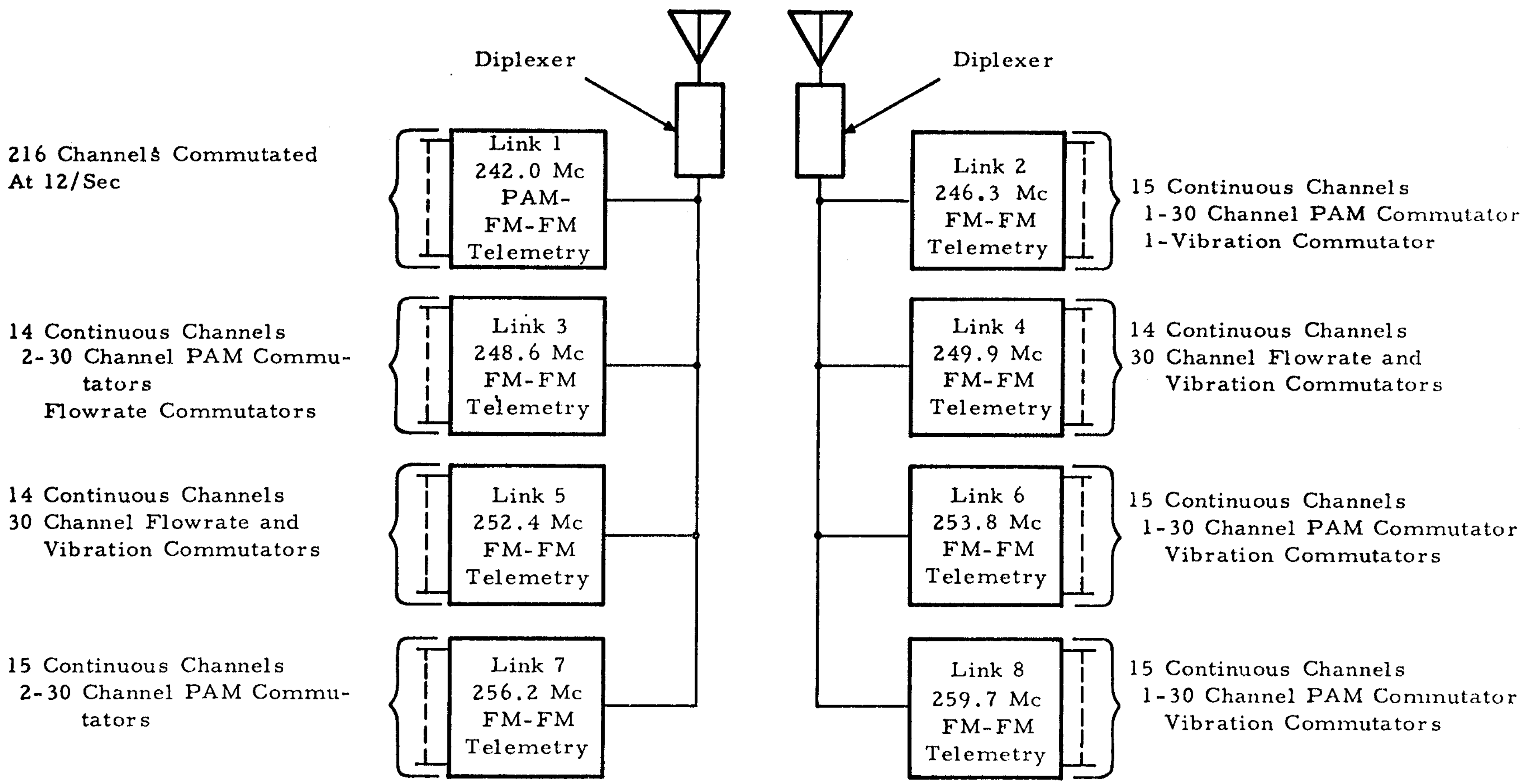


Figure 4-1. The Saturn SA-1 Vehicle Telemetry

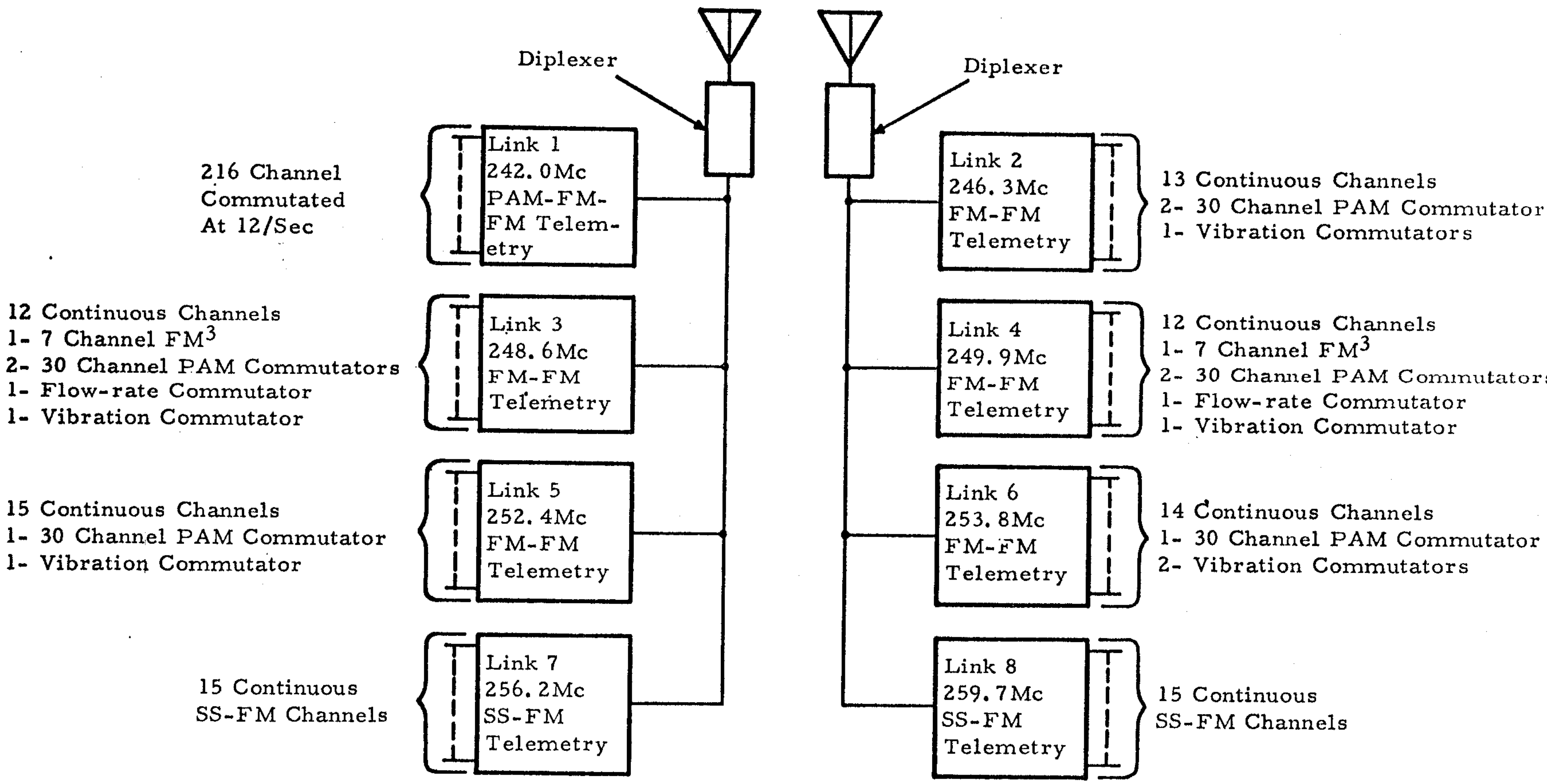


Figure 4-2. The Saturn SA-2 Vehicle Telemetry

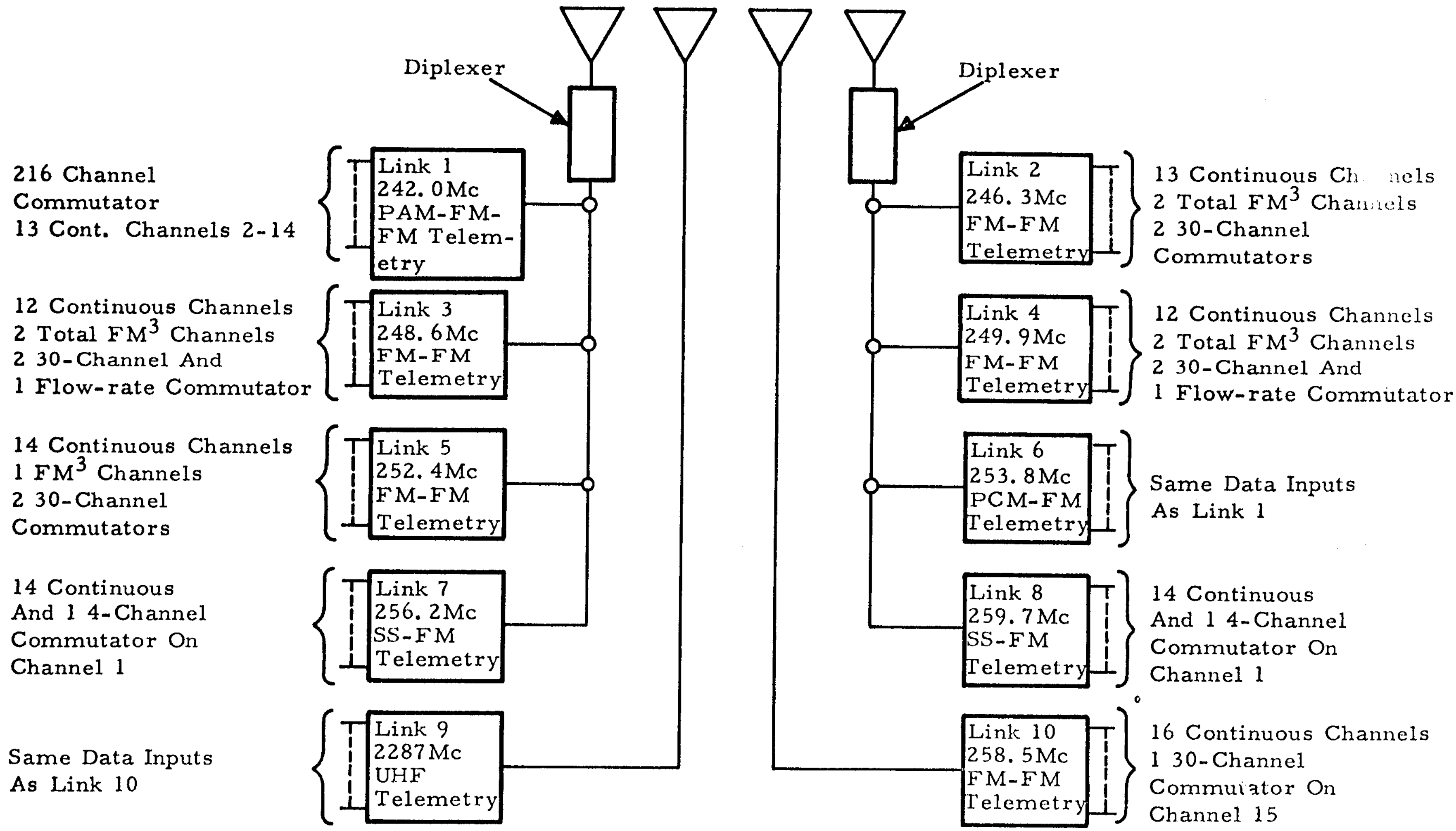


Figure 4-3. The Saturn SA-3 and SA-4 Telemetry

Vehicle	FM^3	Vibration SS-FM	Off-On (Super-Imposed)	Off-On (X0 - 4 Comm)	Off-On (216 Channel)	Low Freq (216 Chan)	Flow Rate Commutator	X0 - 4 Commutator	Continuous FM-FM	Vibration Cont FM	Vibration Commutated	Total
SA-1	-	-	33	20	-	152	24	166	65	30	24	514
SA-2	20	32	26	3	16	168	24	166	51	7	40	555
SA-3	37	28	16	10	-	186	24	221	55	7	8	592
SA-4	37	31	16	-	8	194	24	234	57	7	8	616
SA-5	No Breakdown of Measurements Is Available At This Writing											Est. 1000-1200

Figure 4-4. Saturn Telemetry Measurements

Each of the subcarrier oscillators may be preceded by an additional group of subcarrier oscillators which are modulated by transducer outputs. This allows a number of measurement channels to be transmitted on one subcarrier oscillator, trading channel capacity for bandwidth. Such a system is called FM/FM/FM or FM^3. Figure 4-5 shows a block diagram of an FM/FM link that includes the provision for FM/FM/FM.

PAM/FM/FM

Another method of trading bandwidth for channel capacity is to time-multiplex (commutate) a number of analog measurements and to feed the resulting amplitude-varying pulse train, along with channel identifying sync pulses, into one of the subcarrier oscillators of the FM/FM link. This technique is called PAM/FM/FM (pulse amplitude modulation).

Link 1 PAM/FM/FM telemetry utilizes a 300-channel, solid-state multiplexer, with each channel sampled 12 times per second. This is accomplished by utilizing a 30-channel multiplexer sampled at 120 times per second and submultiplexing each channel with a 10-channel, 12 samples per second submultiplexer. The sampling format is determined by gating pulses fed to the various multiplexers from a programmer.

There are 216 data channels and 84 sync channels at present, with 270 data channels and 30 sync channels planned for the future. Due to the high pulse rate (3600 samples per second) out of the multiplexer, non-standard IRIG modulation of the subcarrier oscillator is required to obtain the necessary bandwidth. Subcarrier oscillator No. 18 (70 kc) is used with the high-capacity multiplexer, with a frequency deviation of ±30 percent. Due to the increased deviation, channels 15 through 17 are not used. Channels 2 through 14 carry continuous signals as the normal FM/FM technique.

The 30-channel commutators, shown as inputs to links 2 through 10, are the same as the high-capacity multiplexer without the submultiplexing. The pulse rate is 300 pulses per second; the channel sampling rate is 10 per second. The four-channel commutators shown as inputs to links 7 and 8 are electronic commutators. Figure 4-6 shows a block diagram of a PAM/FM/FM system.

SS/FM

The large number of high-frequency vibration measurements required by the Saturn program led to the development of a new telemetry technique, adapted from a similar

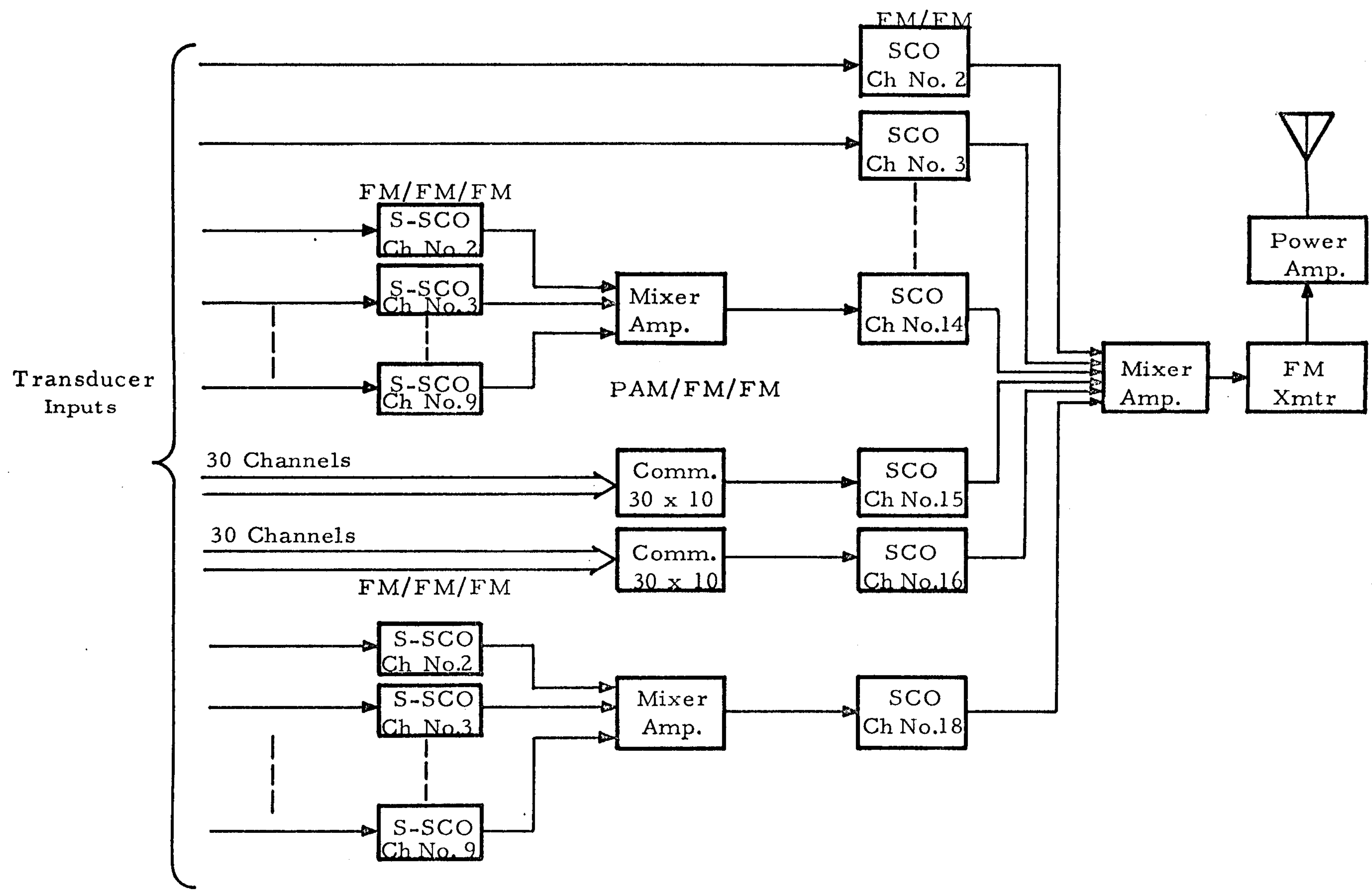


Figure 4-5. FM/FM Telemetry Containing FM/FM/FM and PAM/FM/FM Techniques

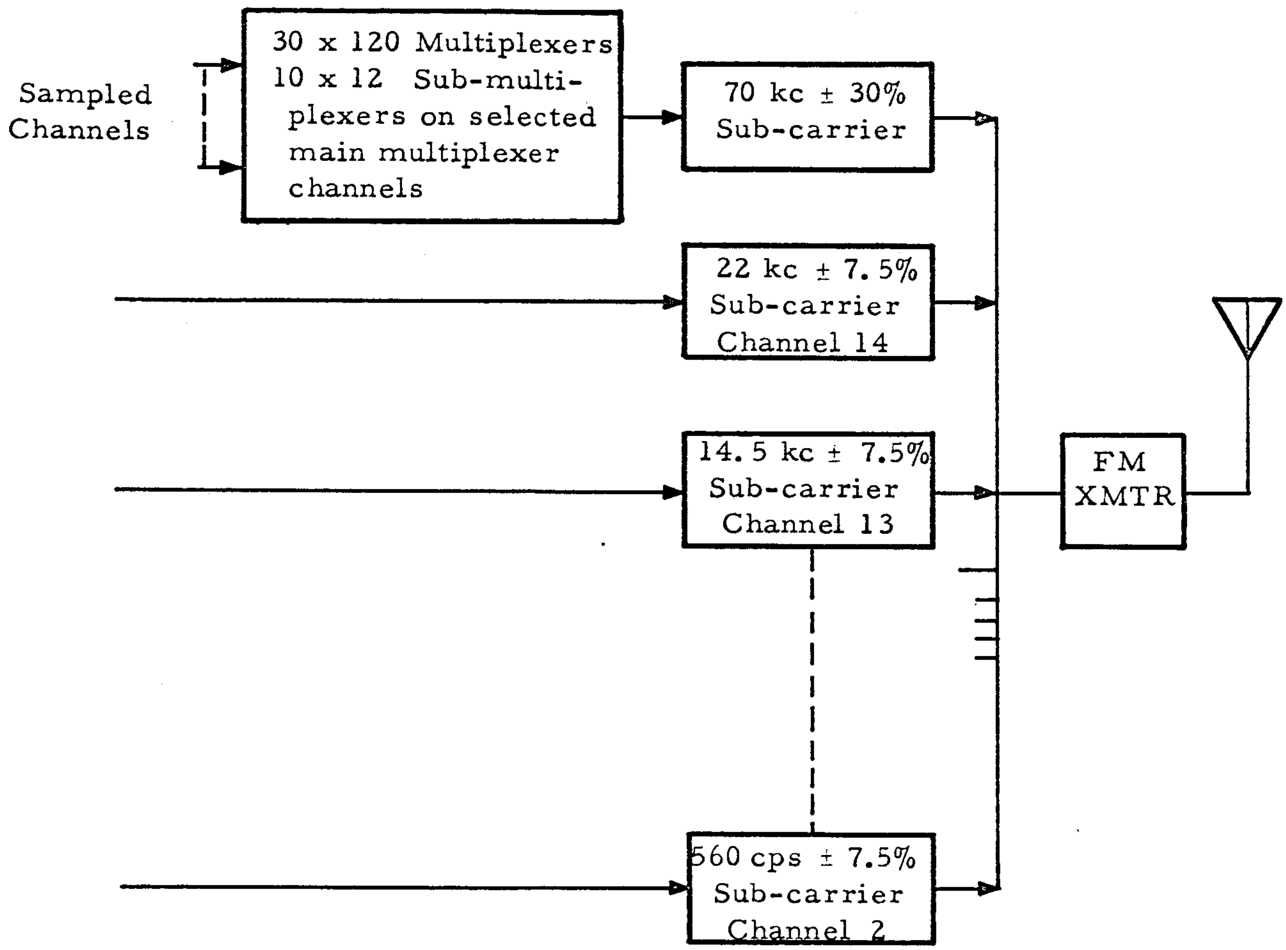


Figure 4-6. The Saturn PAM/FM/FM Telemetry

technique used for many years in carrier telephony. This technique consists of modulating an FM carrier with single sideband AM subcarriers. The bandwidth efficiency of this system is approximately 10 times greater than that of FM/FM.

The single sideband AM/FM (SS/FM) telemetry system can transmit 15 channels of full spectrum (30 to 3000 cps) of vibration data within the standard telemetry carrier bandwidth specifications.

A block diagram of the SS/FM link is shown in Figure 4-7. The data input of each channel is fed into a balanced modulator and is heterodyned with a 455-kc carrier. The sum and difference signals appear in the output, and the bandpass filter passes the upper sideband only. This frequency was chosen to utilize standard tooling in the manufacture of the mechanical filters. The second modulator translates the data to an assigned baseband frequency by utilizing the outputs of the frequency synthesizer.

The frequency synthesizer generates 15 carriers for the second modulator plus a synchronizing tone for the ground equipment. To accommodate a 3-kc information bandwidth with sufficient guardband, a channel spacing of 4.74 kc is used.

PCM/FM

The PCM/FM system, shown as link 6 in Figure 4-3, will transmit redundant information on flight SA-3 and SA-4 for flight certification of the equipment. The PCM system consists of one or more of the previously described multiplexers, an analog-to-digital converter, a programmer, and an FM transmitter.

A block diagram of the PCM/FM link is shown in Figure 4-8. The programmer utilizing a reference clock frequency, sends gating pulses to the multiplexers which allow sampling of each individual data channel at a predetermined rate and sequence. The resulting analog pulse train is fed into the analog-to-digital converter, where each pulse amplitude representing a sample of a particular channel is converted into a binary-coded digital word. The resulting digital pulse train from the analog-to-digital converter, along with guidance computer words already in digital form, discrete event signals, and synchronizing pulses (all placed in the proper time sequence by the programmer) are converted to a non-return to zero (NRZ) wave train which directly frequency-modulates the FM carrier.

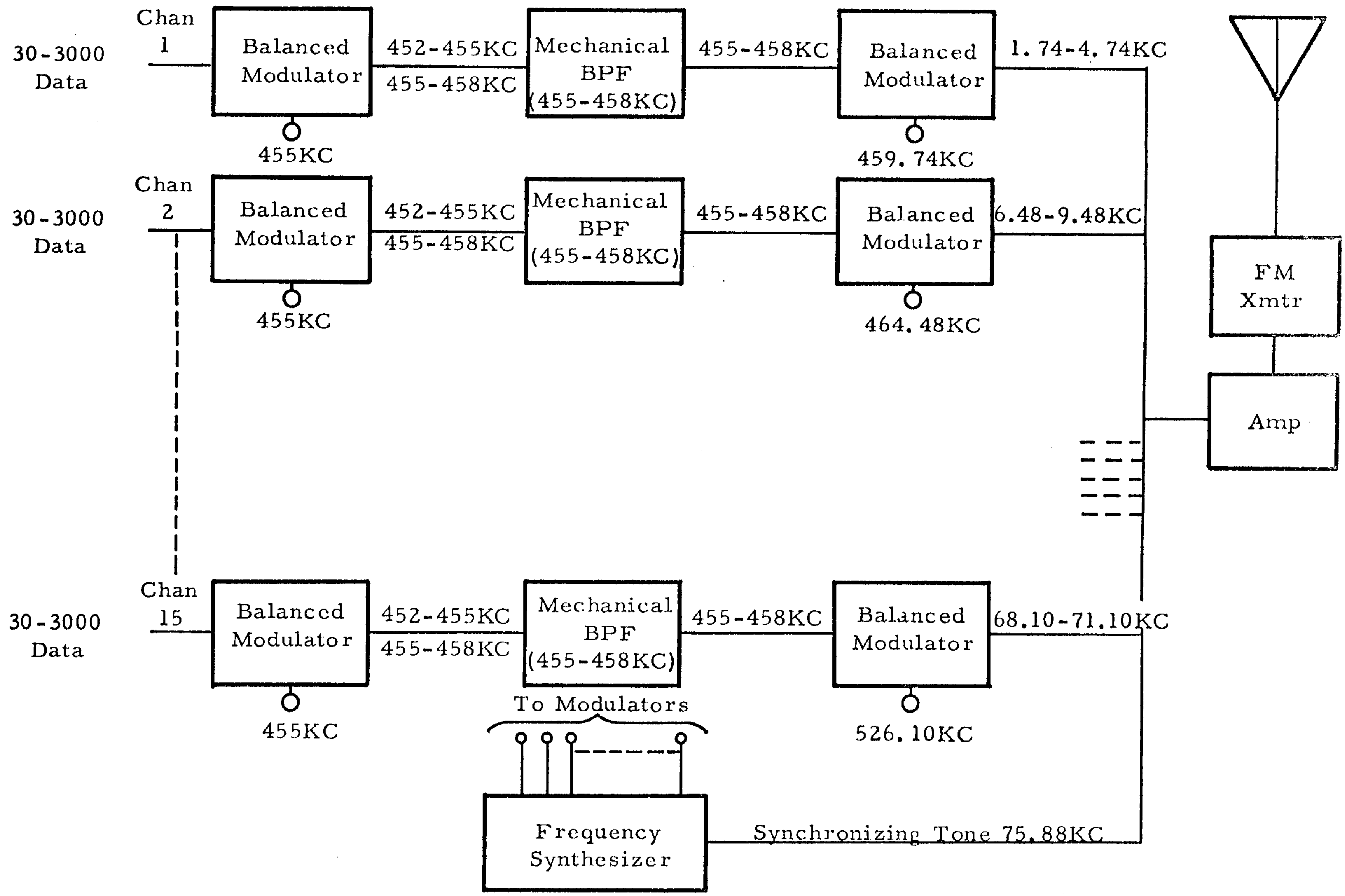


Figure 4-7. SSB/FM Telemetry for Vibration and Other Wide-Band Data

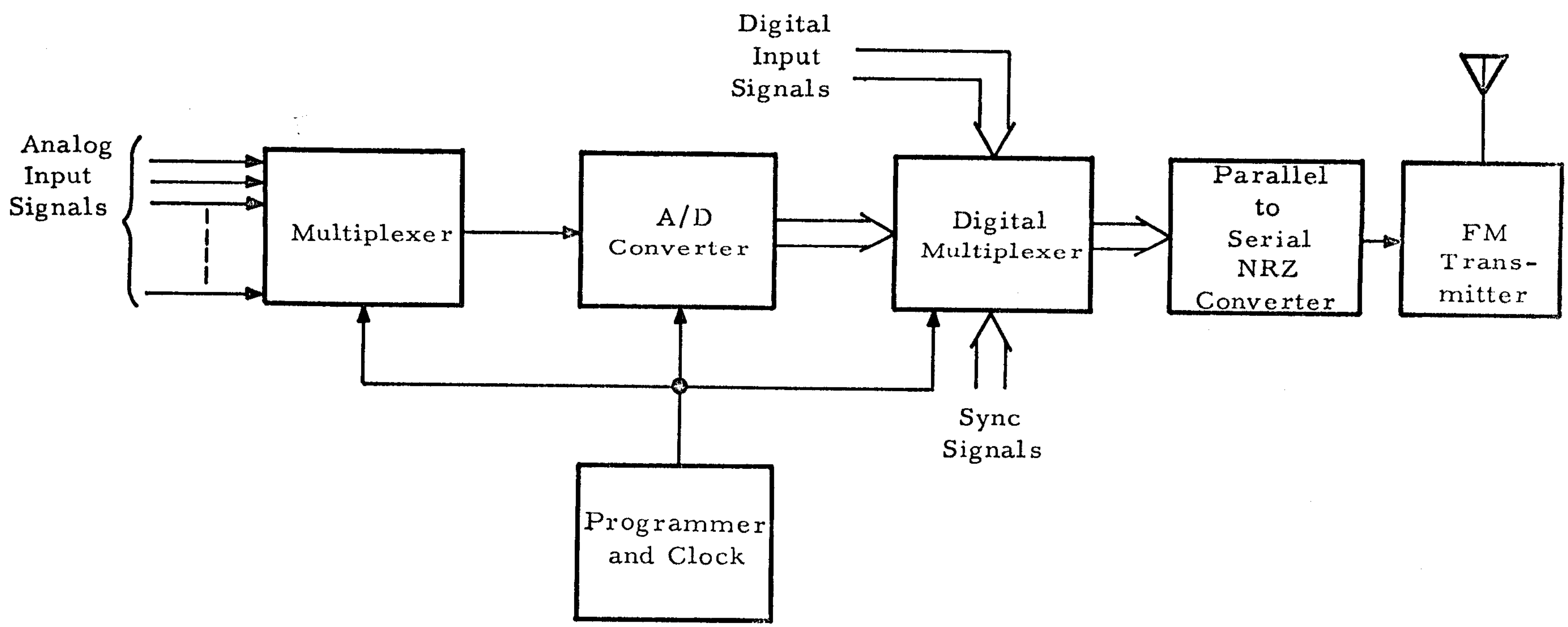


Figure 4-8. PCM/FM Telemetry

UHF/TM

Link 9 is an experimental data link to be evaluated on SA-3 and SA-4. Sometime before mid-1970, the entire telemetry band must be shifted from VHF to UHF frequencies. In line with their past policy of using tested, reliable hardware, NASA will carefully scrutinize the results of these first attempts to use UHF telemetry gear. For the present program, the UHF effort will be redundant to insure that no loss of data results. This link will transmit the same information as does link 10 by utilizing the composite outputs of the subcarrier oscillators used in link 10.

The UHF transmitter is a commercial unit capable of ±500-kc deviation; however, ±125-kc deviation will be used in order to obtain an equivalent signal-to-noise ratio for comparing the two paralleled systems.

PRIMARY GROUND STATION

There is a LOC-operated telemetry reception station located in LOC's Hangar D. The station now has 16 receivers, giving 100 percent back-up. Plans are to expand at such a rate as to maintain this back-up percentage. A block diagram of this facility is shown in Figure 4-9. Two tri-helix telemetry antennas on SCR-584 mounts are positioned manually to receive the transmitted data. Each antenna is connected to a wide-band preamplifier on the antenna mount. These, in turn, feed multicouplers whose outputs are connected individually, at present, to a bank of eight Nems-Clarke receivers, each tuned to the appropriate RF telemetry link. The outputs of these receivers can be connected during checkout or flight operation to Ampex FR600 7/14 channel tape recorders. Any two of the links can also be patched to the two banks of EMR subcarrier discriminators and, in turn, to CEC recorders for real-time readout of pertinent information. Time-multiplexed channels can be decommutated and recorded. A box-car type circuit is used to maintain the recorded amplitude at the last sampled level of the time-multiplex input to provide more continuity in the recording. In addition, information for computer processing will be available for future real-time equipment checkout.

Hardlines to the Saturn pad are available for closed-loop checkout when radiation is not permissible. Open-loop checkout of the system is also accomplished when recording of any of the links is desired.

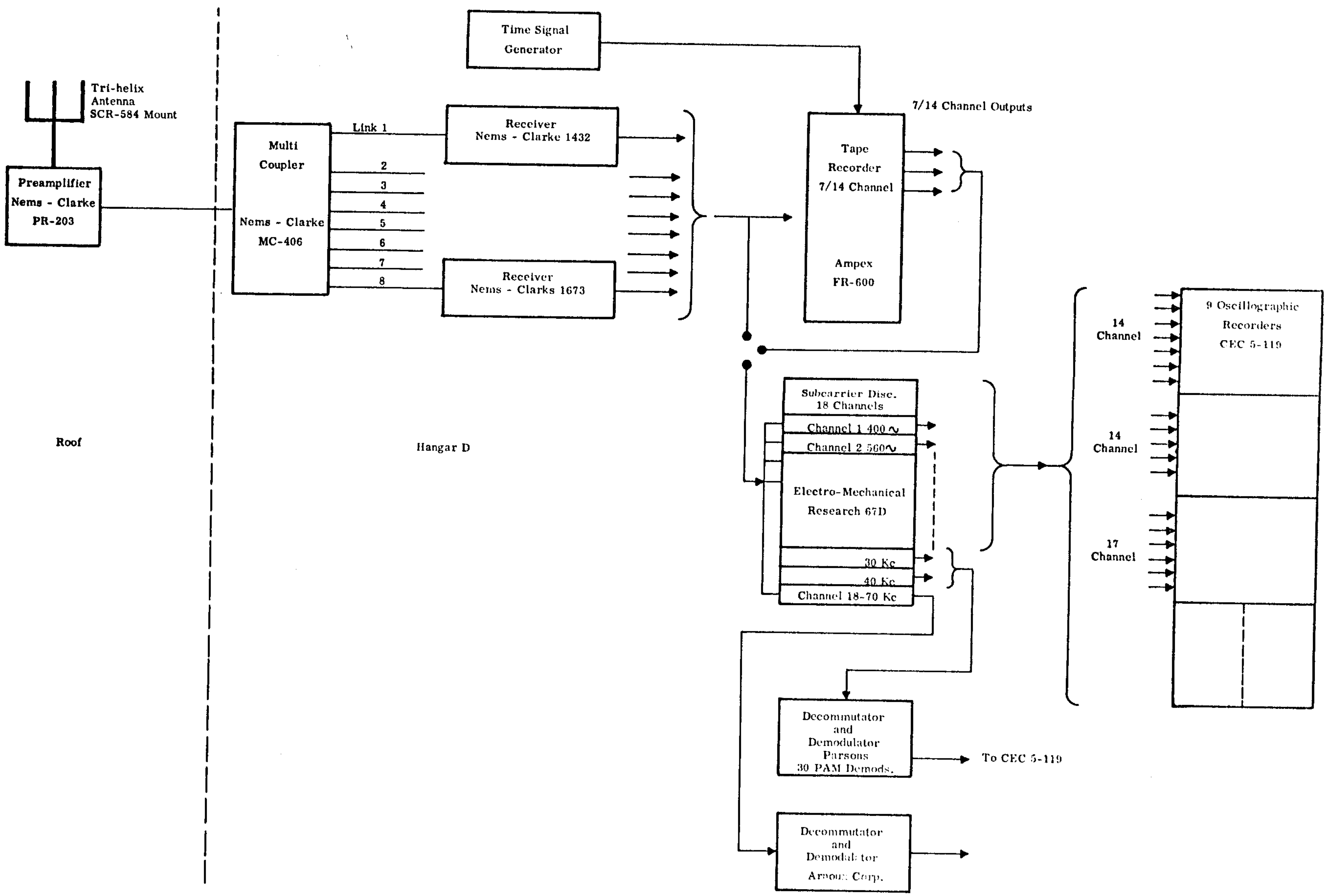


Figure 4-9. Primary Ground Station

BLOCKHOUSE CHECKOUT SYSTEM

The blockhouse is used to monitor and calibrate the on-board telemetry equipment. No strip-chart recordings are made but receiver outputs can be recorded on tape for further analysis at the primary ground station. The entire vehicle system can be checked out through the use of closed-loop hardlines from the missile to the blockhouse or by means of a seven-turn bifilar helix antenna during radiation checkout. Radiation operation is coordinated with AMR and with the RF group. Both open- and closed-loop checkouts must be cleared by AMR. A block diagram of the blockhouse equipment is shown in Figure 4-10.

CHECKOUT AND MAINTENANCE PHILOSOPHY

In contrast to the point-by-point, black box checkout accomplished at MSFC, the approach taken at LOC is system oriented. The operation of individual units is not checked but rather the system operation as a whole is monitored. The vehicle arrives with the telemetry installed. The philosophy is not to remove the equipment but to check it in the vehicle if possible. Necessary repairs are performed in the vehicle if possible. Spare telemetry equipment is available for substitution if required. Since there is no complete standardization of this equipment, the spares may require minor modification prior to installation in the vehicle, if such installation becomes necessary due to faulty operation of the original equipment.

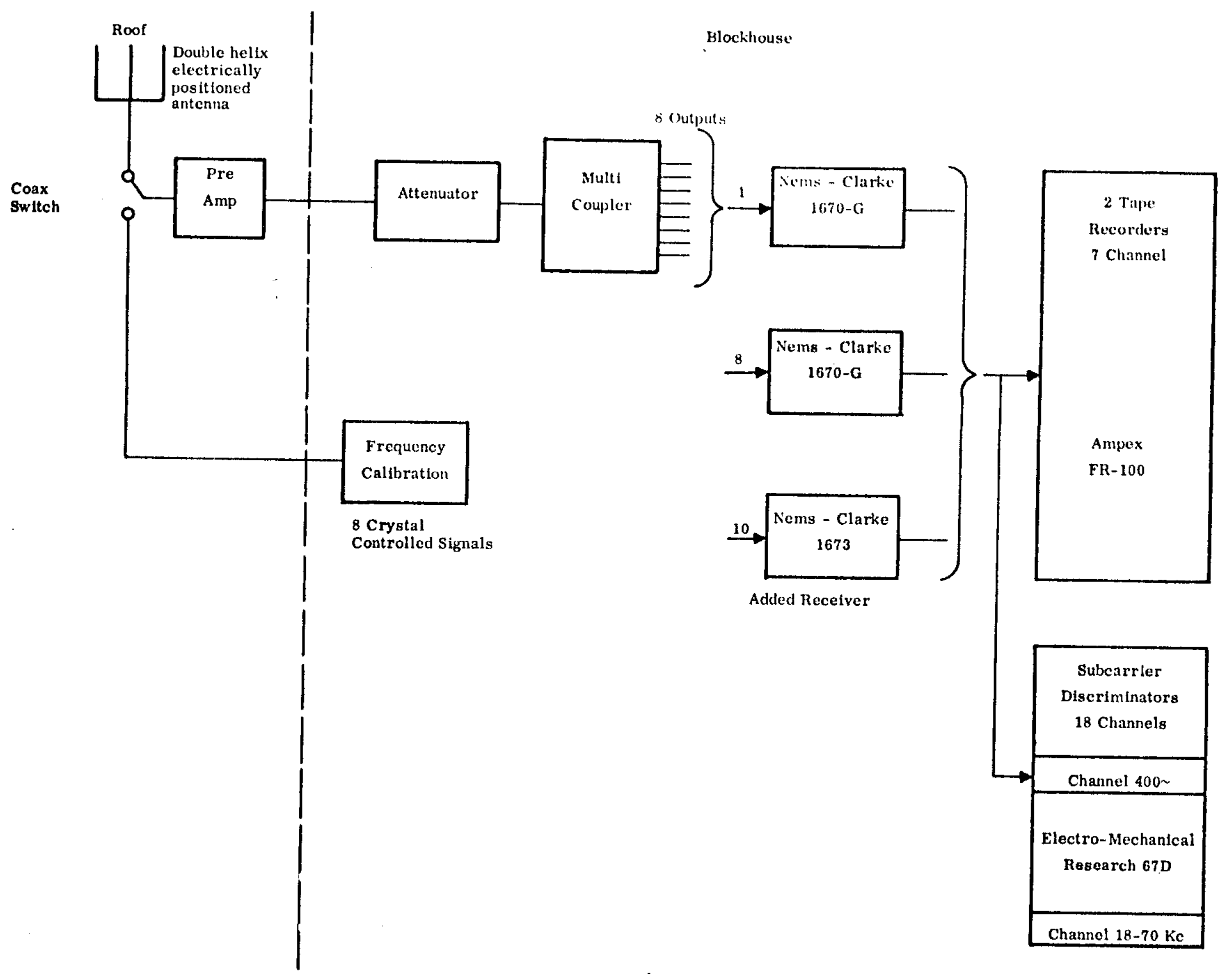
DESCRIPTION OF TESTS PERFORMED ON VEHICLE TELEMETRY SYSTEM

Documentation

Documentation concerning the telemetry system of the launch vehicle is obtained from the Astrionics Division of Marshall Space Flight Center. The documentation is reviewed thoroughly and the vehicle telemeter test equipment is modified, if necessary, in order to perform the required testing of the vehicle telemetry system. Test descriptions and results are recorded in a log. All malfunctions of the vehicle telemetry system and its antenna system are reported by means of unsatisfactory condition reports.

Initial Testing of the Vehicle Telemetry System

All cables connecting to the vehicle telemetry system are inspected to insure that they are connected properly. All accessible fuses in the vehicle telemetry system are



Tape Format

Channel	A	B	
1	Timing	Timing	
2	Link 1	Link 5	
3	2	7	
4	3	8	
5	4	10	
6	Y2	Y2	Hard lines to Hangar D
7	Y1	Y1	

8 WB pairs to Hangar D for transmitting video signals.

Figure 4-10. Blockhouse

checked to insure that they are properly rated. The voltage standing-wave ratio of each antenna is measured at the antenna connector. This measurement is taken using the highest, lowest, and mid-range frequencies that the particular antenna is to transmit.

The vehicle telemetry system is connected to transmit the RF telemetry signals through the antenna system if open-loop frequency clearance has been obtained from the range. The system is connected to transmit the RF telemetry signals through a coaxial cable to the launch-complex telemetry checkout system if open-loop frequency clearance is not available, but closed-loop frequency clearance is available from the range. Some tests are run closed-loop regardless of frequency clearance. The insertion loss of each multicoupler channel is checked by comparing input power at the proper frequency with the resulting output power. The voltage standing-wave ratio of each antenna system is measured at the input of the power divider. This measurement is taken using the highest, lowest, and mid-range frequencies that the system is to transmit.

While all telemeters in the vehicle telemetry system are operating, the following items are performed at the telemetry receiving station:

- The relative indicated signal strengths of the telemeters are noted.
- The pre-emphasis of each subcarrier is checked by the use of subcarrier discriminators which have been calibrated with respect to input levels.
- The carrier frequency of each of the telemetry transmitters is measured.
- The telemetry signals are observed for quality of the signals and for any indication of malfunctions in the vehicle telemetry system.
- A magnetic tape recording of the telemetry signals is made while pre-flight and in-flight calibration is applied to the vehicle telemetry system.
- A magnetic tape recording of the telemetry signals is made while simulated information is applied to each telemeter input channel in sequence. Application of the simulated information to each telemeter input channel is accomplished by connecting a "continuity sequencer" in the vehicle telemeter system.

The magnetic tape recordings are played back through demodulation and decommutation equipment and the outputs of this equipment are recorded on oscillographic recorders. Also, during the playback of the magnetic tape recordings, the pulse rates of the commutators used in the vehicle telemetry system are checked by Lissajous figures.

Evaluation of Test

The oscillograph records are examined to determine the following:

- Excessive noise and intermodulation is not present.
- The telemeters are functioning properly.
- Internal wiring of the telemeters is correct.
- The calibration programming of the telemetry channels agrees with that called for in the measuring program.
- The high and low band edges of each subcarrier oscillator in the system is within tolerance.
- All relays and solid-state switching devices in the system are operating properly.

The oscillograph records are kept on file for future reference.

Ground Instrumentation Test

The access doors on the vehicle are secured. The RF, tracking, and telemetry systems are all operated simultaneously and radiate through their respective vehicle antenna systems. The telemetry receiving stations check for any interference with the telemetry signals and check telemetry-radiation signal strength. Another purpose of the test is to resolve any possible problems which may arise in connection with range criteria.

Over-all Tests

Prior to all over-all tests in which the vehicle telemetry system participates, a short test is made on the telemetry system to determine that it is operating properly.

Telemetry signals that are recorded during the over-all test are played back onto oscillographic recorders. The oscillograph records are examined to determine whether the telemetry systems operated properly during the test.

Simulated Flight Test

Prior to the simulated flight test, all cables which connect to and are within the vehicle telemetry system are inspected to insure that they are connected properly for launch of the vehicle. These cables are not disconnected again prior to launch unless absolutely necessary.

Just prior to the simulated flight test, a test is made on the vehicle telemetry system to determine that it is operating properly. The simulated flight test is performed with the telemetry system radiating through its antenna system. Oscillograph recordings are made and examined thoroughly.

Launch Countdown

The telemetry system is operated for several short tests during the launch countdown to determine that the system is operating properly.

Spare Vehicle Equipment

Spare components for the vehicle telemetry system and telemetry antenna are supplied by the Astrionics Division of the Marshall Space Flight Center. These components are tested in the vehicle telemetry laboratory at LOD. They are tested thoroughly, using procedures similar to those used for the vehicle telemetry-system equipment. After having been checked out, these spare components are kept on hand for immediate installation in the vehicle, should it be necessary.

Major Test and Recording Equipment

- Telemetry Receivers, Nems-Clarke, Model 1432
- Telemetry Receivers, Nems-Clarke, Model 1670
- Preamplifiers, Nems-Clarke, Model PR-203
- Multicouplers, Nems-Clarke, Model MC-406
- Magnetic Tape Recorder/Reproducer, Ampex Model FR-614
- Magnetic Tape Recorder/Reproducer, Ampex Model FR-107
- Subcarrier Discriminators, Electro-Mechanical Research, Model 67D
- Tri-Helical Antennas
- Single Helix Antennas
- Oscillographic Recorders, Consolidated Electrodynamics Corporation
- Decommutator, Arnoux, Series 300
- Decommutator, Parsons, Model 5251
- Oscilloscopes
- Wattmeters
- FM Signal Generators
- Reflection Coefficient Meter
- VHF Bridge
- Telemetering Indicators, Panoramic Radio Products, Model TMI-1a
- General Electric 225 Computer (used in Telemetry System Checkout)

PLANNED COMPUTER PROGRAM

Future checkout plans indicate automation of telemetry data processing. For SA-3, 13 lines from the primary ground station to the computer will be utilized. The telemetry information will be coded in 10-bit binary. The remaining lines will be used for control and timing signals. The program will facilitate the checkout of the 30-channel and 300-channel PAM/FM commutated outputs of the SA-3 system. The computer analysis will be performed during all telemetry tests. A block diagram of this system is shown in Figure 4-11.

Future expansion is planned for this program to include provision for PDM and PCM information available from SA-5. In addition to 10-bit binary data transmission, there will be 12-bit binary address information with capability thereby of monitoring 4096 channels. At this time, it is envisioned that a maximum of 2048 channels would be monitored. A block diagram of this system is shown in Figure 4-12.

High and low values of all monitored information will be stored in the computer. Any deviations from these norms will be printed out. Information on print-out will include measurement number, instrument, high value, low value, measured value, and time of recording. This time will be real-time or, if from a monitored recording, the tape time.

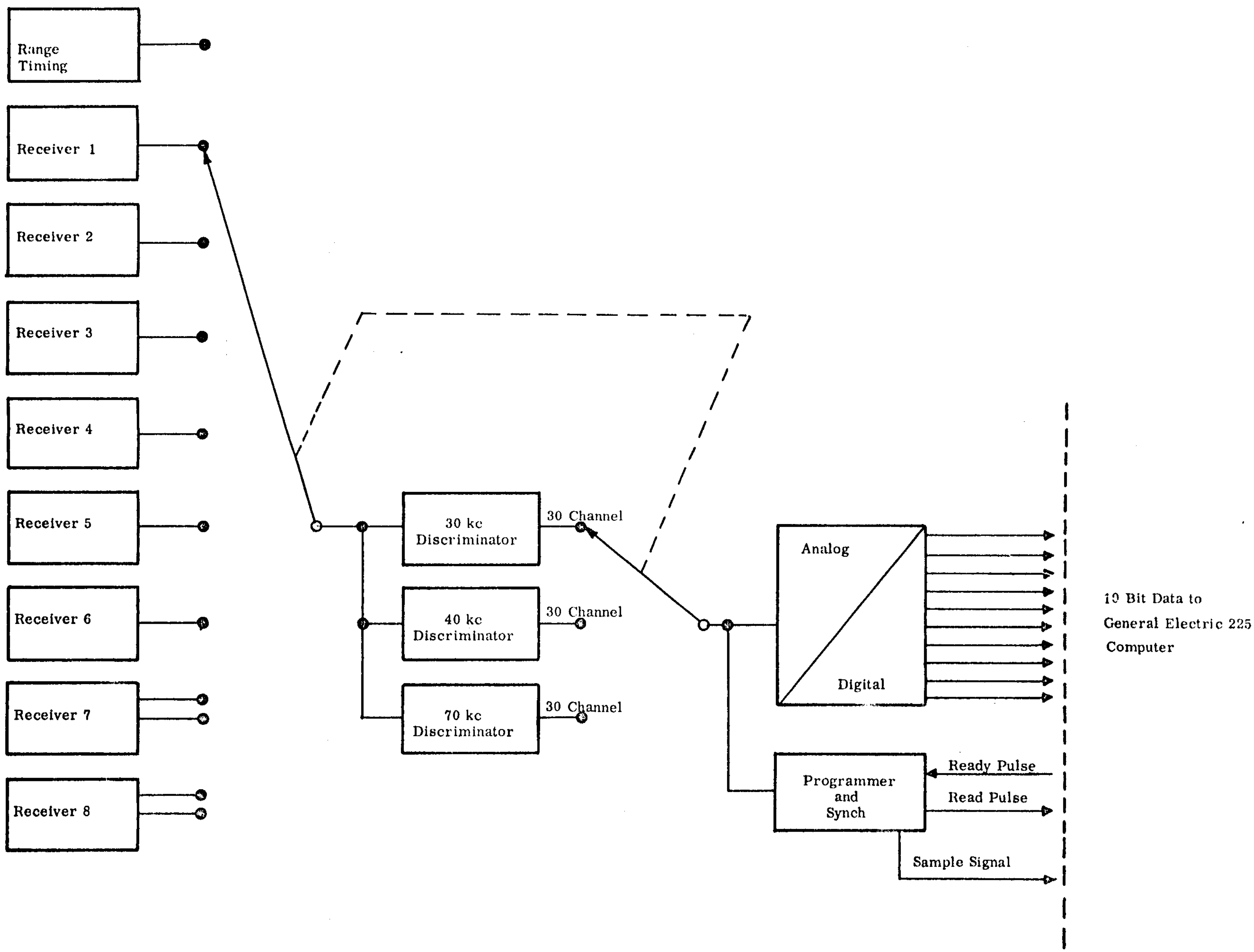


Figure 4-11. SA-3 Computer Program

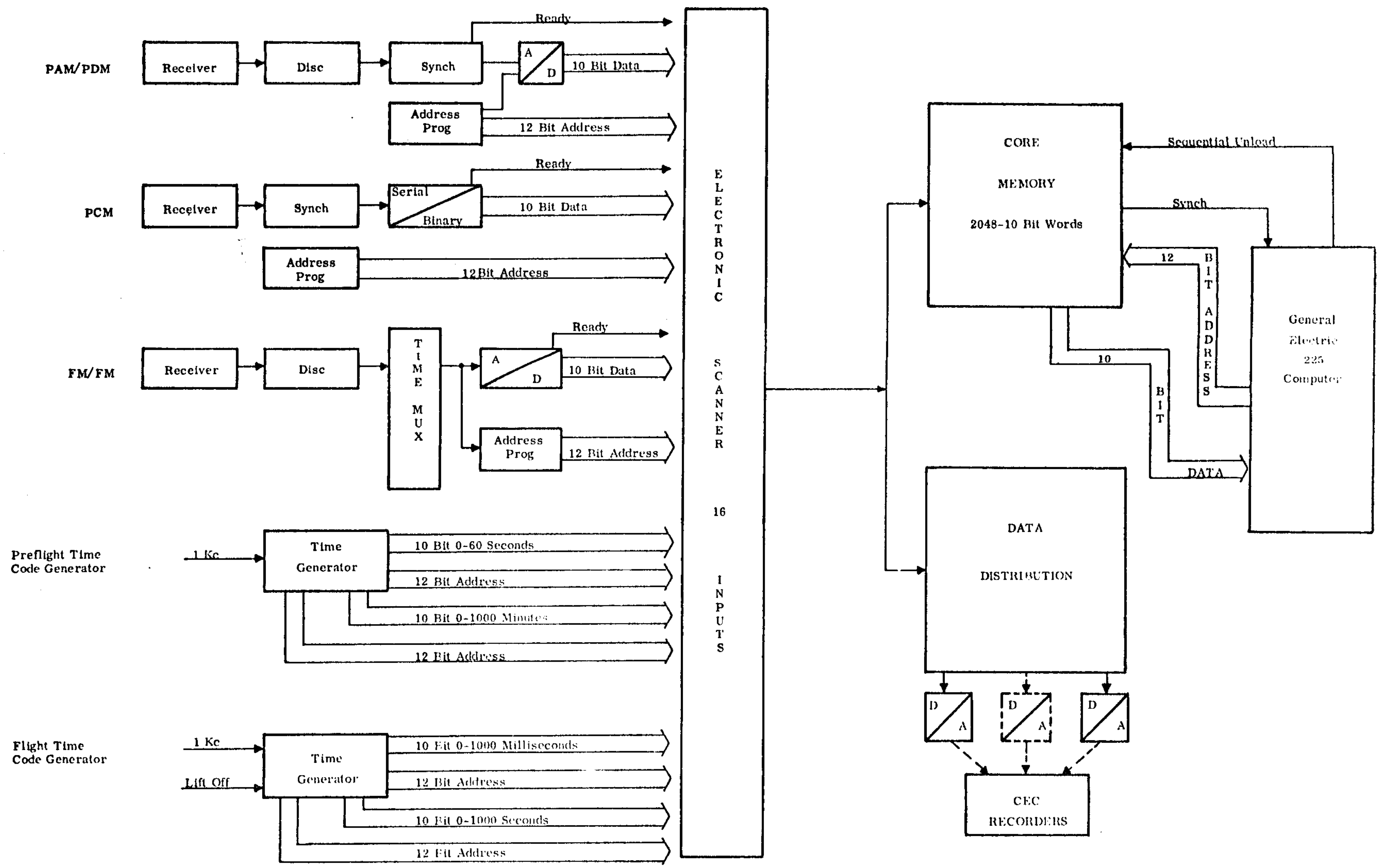


Figure 4-12. SA-4 and SA-5 Computer Program

AZUSA

TECHNICAL DESCRIPTION

System Description

The Azusa II System is a precision electronic tracking system. The ground systems, working with a missileborne transponder, utilizes phase-comparison techniques to determine missile position, velocity and acceleration. A system block diagram is shown in Figure 4-13. These data are used in real-time for impact prediction and are recorded to provide post-flight metric data.

The equipment measures range, coherent range, two direction cosines, and two cosine "rates." Phase delay of a modulation frequency is measured to determine range. Doppler count determines coherent range. Phase differences of the transponder signal arriving at ground antennas (precisely spaced along two mutually perpendicular, intersecting baselines) are measured to obtain direction cosines and cosine "rates." The antenna baseline array includes an automatic tracking antenna of the conical-scan type. This auto-track antenna is located at the intersection of the baselines, and is used to "point" all other antennas of the system, including one antenna that is used to transmit the frequency-modulated carrier to the missileborne transponder.

The function of the transponder in the missile is to receive and demodulate the frequency-modulated carrier from the ground station. The signal thus derived is used to modulate the transmitter portion of the transponder.

The separation frequency between the transponder's receiver and transmitter in non-coherent models is approximately 60 Mc. In coherent types, separation frequency is approximately 60.2 Mc. The 0.2-Mc difference between the two models results from the fact that in the coherent model, the frequency difference between input and output RF is phase locked to a multiple of the fine modulation frequency. This frequency received at the ground station can be measured and compared to the same multiple of modulation used in the transponder to provide incremental measurements of range.

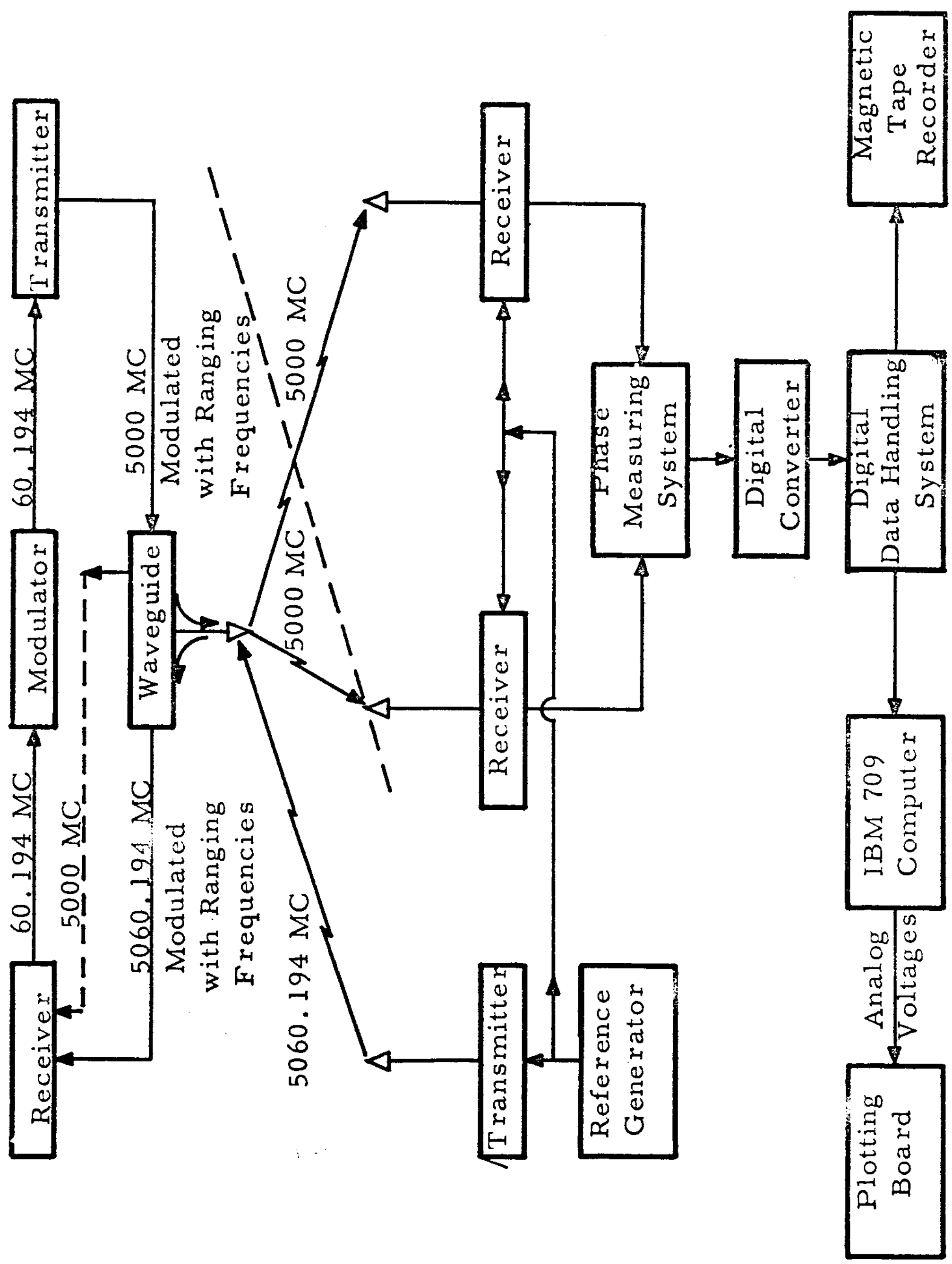


Figure 4-13. Azusa System Block Diagram

Each of the ground-station baselines consists of three antenna pairs spaced at 5 meters, 50 meters, and 500 meters. The 50-meter and 500-meter pairs of each baseline have one antenna in common, and the conical-scan antenna provides reference for 5-meter pairs in both baselines. Utilizing the antennas in this manner, the system requires nine receiving antennas and one transmitting antenna.

The conical-scan antenna tracks 360 degrees in azimuth and approximately 85 degrees in elevation and it provides ambiguity resolution for the 50-meter baseline, which is the precision data baseline. The 500-meter baseline will provide incremental cosine information for use in computing cosine rate data.

The target is acquired, initially, by using the local MC 51 optical tracker or by using radar acquisition information transmitted to the site by landline. The tracking problem is more complex than the acquisition problem. Since the conical-scan antenna is sensitive to both polarity and signal strength, the radiating pattern of the missileborne antenna is the greatest limiting factor in maintaining reliable track. In order for the system to remain locked on target, the missile antenna pattern should not at any time during flight exhibit nulls greater than 10 db to the ground-station equipment. Nulls greater than 10 db in the missileborne antenna pattern can also cause serious degradation of data quality. Polarization of the ground-system antenna is set to an optimum angle prior to flight, but cannot be changed during flight. If the polarization of the signal received at the ground station changes more than 90 degrees during flight, the system may lose lock, and complete loss of the signal may occur. If the system is to perform reliably and obtain data of optimum quality, exacting design of the missileborne antenna is necessary to provide an antenna pattern that has a broad beam and shallow null configuration. It is desirable that the missile antenna be circularly polarized.

The following data has been gathered from Azusa II:

a. Missile parameters measured:

l = cos a

m = cos B

r = slant range

r_m = modulation slant range (nonambiguous)

r_{cc} = incrementally derived range

l_e = incremental cosine from extended baseline

m_e = incremental cosine from extended baseline

t = time increment between data samples

b. Missile parameters computed at AMR:

$\dot{n}$ = cosine rate

$\dot{r}_{cc}$ = radial range rate

$\dot{l}_e$ = l cosine rate

$\dot{m}_e$ = m cosine rate

$x, \dot{x}$ = Cartesian coordinates of position and velocity

$y, \dot{y}$ = Cartesian coordinates of position and velocity

$z, \dot{z}$ = Cartesian coordinates of position and velocity

System Specifications

System specifications are given below:

Range:	1000 n. mi.
Range resolution:	0.1 foot ambiguous
	1.0 foot nonambiguous
Angle resolution:	2 (10^{-6}) in l or m nonambiguous
	2 (10^{-7}) incremental l_e or m_e
Azimuth rate:	1.0 radian/sec
Elevation rate:	0.4 radian/sec
Cosine rate:	0.1 radian/sec
Tracking rate:	30,000 ft/sec in range
Power output:	3,000 watts input to the transmitting antenna
Receiver sensitivity:	160 dbw at the receiver antenna
Coverage:	hemispherical to 2 degrees elevation
Antennas:	1 parabolic conical-scan receiving antenna, gain 35 db.
	8 parabolic receiving antennas slaved to the conical-scan antenna, gain 35 db.
	1 parabolic transmitting antenna slaved to the conical-scan antenna, gain 35 db.

Frequencies:

Ground Station	
Transmitter:	5060 ±0.75 Mc - receiver
Receivers:	5000 ±0.75 Mc - transmitter
FM modulation:	98.3565 kc (fine-range modulation) on continuously.
	3.93 kc (intermediate-range modulation) on for ambiguity resolution of fine-range modulation.
	157 cps (coarse-range modulation) on for ambiguity resolution of intermediate-range modulation.

Ambiguities of the different baselines are as follows:

Conical scan:	Nonambiguous
Coarse, 5-meter baselines:	Ambiguous for each 12,000 ppm in direction cosine.
Fine, 50-meter baselines:	Ambiguous for each 1200 ppm in direction cosine.

Range ambiguities are resolved by using lower frequency modulations which are phase locked to the fine data-modulation frequency. Ambiguities in range are as follows:

Coarse, 157-cps data:	Ambiguous for each 3,125,000 feet of range.
Intermediate, 3.93-kc data:	Ambiguous for each 125,000 feet of range.
Fine, 98.356-kc precision data:	Ambiguous for each 5,000 feet of range.

AZUSA CHECKOUT PHILOSOPHY

The Azusa transponder is installed in the Saturn vehicle at MSFC and undergoes complete checkout prior to shipment to Cape Canaveral.

Upon arrival at Cape Canaveral this transponder is removed from the vehicle and taken to GDA-Azusa Service Center where it is completely checked by GDA personnel using the test set specially designed for the Azusa transponder. This activity is monitored by LOC personnel. Included in this check is an air link check with the Azusa ground system.

Upon return to LOC, the transponder is re-installed in the vehicle.

Standard and specialized equipment is available at the blockhouse for checking the proper installation and functions of the transponder. VSWR measurements are made on the antenna system.

During checkout, the compatibility of the transponder and ground station is once again validated using the missile antenna system. Intra-vehicle and inter-system RF interference is checked during vehicle system testing.

In general, the Azusa transponder is a reliable, proven equipment and very little difficulty is encountered with it. A spare transponder is shipped with the vehicle and is installed if the installed transponder fails.

The following Azusa checkout procedure is now in use.

AZUSA CHECKOUT

Prior to the Erection of the Vehicle at the Complex

a. Measure attenuation and VSWR of the checkout cable from the RF room in the structure to the first platform.
b. Verify the calibration of the Azusa checkout set.
c. Verify the operation of the monitor equipment at the Launch Control Center.

Bench Checkout of the Transponder

a. After erection of the vehicle on the pad, remove the Azusa transponder.
b. Take the transponder to the Azusa service center.
c. Monitor the bench test and open-loop checkout of the transponder at the service center.
d. After completion of the checkout, re-install the transponder on the vehicle.

Vehicle Installation Check

a. Measure the attenuation and VSWR of the vehicle Azusa antenna system.
b. Using the Azusa checkout set, measure the coherent threshold sensitivity of the transponder.
c. Arrange an open-loop test, using the MK II Azusa ground station.
d. Make a transponder AGC calibration.

RF Instrumentation Test

a. Verify that the Azusa transponder is connected for open-loop operation.

b. Monitor operation of the transponder during both tests.

OAT No. 3 and No. 4

Connect Azusa transponder for closed-loop operation. Using Azusa checkout set, perform a functional check of the transponder and monitor its performance.

SFT

a. Prior to the test, verify that the Azusa transponder is connected for open-loop operation.

b. Monitor operation of the transponder during the test.

UHF DOPPLER AND POSITION MEASURING SYSTEM (UDOP)

TECHNICAL DESCRIPTION

UDOP is a continuous-wave electronic tracking system which utilizes the integrated Doppler effect to obtain range-sum of range-difference measurements. A system block diagram is shown in Figure 4-14. The system was implemented at the Atlantic Missile Range by ABMA as an improved UHF version of the earlier DOVAP system. The station geometry consists of two independent arrays. One array, consisting of seven receivers and a transmitter within a 20-mile radius of Carter Cay, furnishes the terminal trajectory data. The UDOP system located in the Cape Canaveral area is operated by NASA. The downrange system is operated by the range contractor.

In the UDOP system the transmitter utilizes a frequency standard as a basis for the system frequencies. The output of this standard is frequency multiplied to 50 Mc and transmitted to the various receiving sites as a synchronizing reference signal. The 50-Mc signal is further multiplied at the transmitter site to 450 Mc, at which point it is amplified and radiated to the airborne transponder as an interrogation signal. The transmitter is capable of radiating 1 kilowatt signal, but in normal practice a power level of 700 to 800 watts is used.

The transmitting antenna is a single helix. It is circularly polarized and has a gain of 12 db. The beamwidth is ±15 degrees and will be pointed along the line of flight. The transponder receives the radiated signal with a 450-Mc receiver. The received signal is doubled in frequency, amplified, and reradiated at 900 Mc. The transponder return is received at the UDOP receiving sites at 900 Mc and is compared with the 18th harmonic of the 50-Mc reference signal. The frequency difference between these two signals is directly related to the rate of change of vehicle position. The resulting signal has an approximate range of 0 to 40,000 cps, depending on missile velocity.

The receiver is a Resdel Engineering Corporation (Pasadena, California) UDOP ground receiver, model 90191. The receiving system has no preamplifier. The receiving antennas are scaled-down Andrews Antenna Corporation tri-helix telemetry antennas. They are circularly polarized, with a beamwidth of ±12 degrees for the 3-db down points and have a gain of 18 db.

These antennas are manually oriented to the nominal trajectory during the flight.

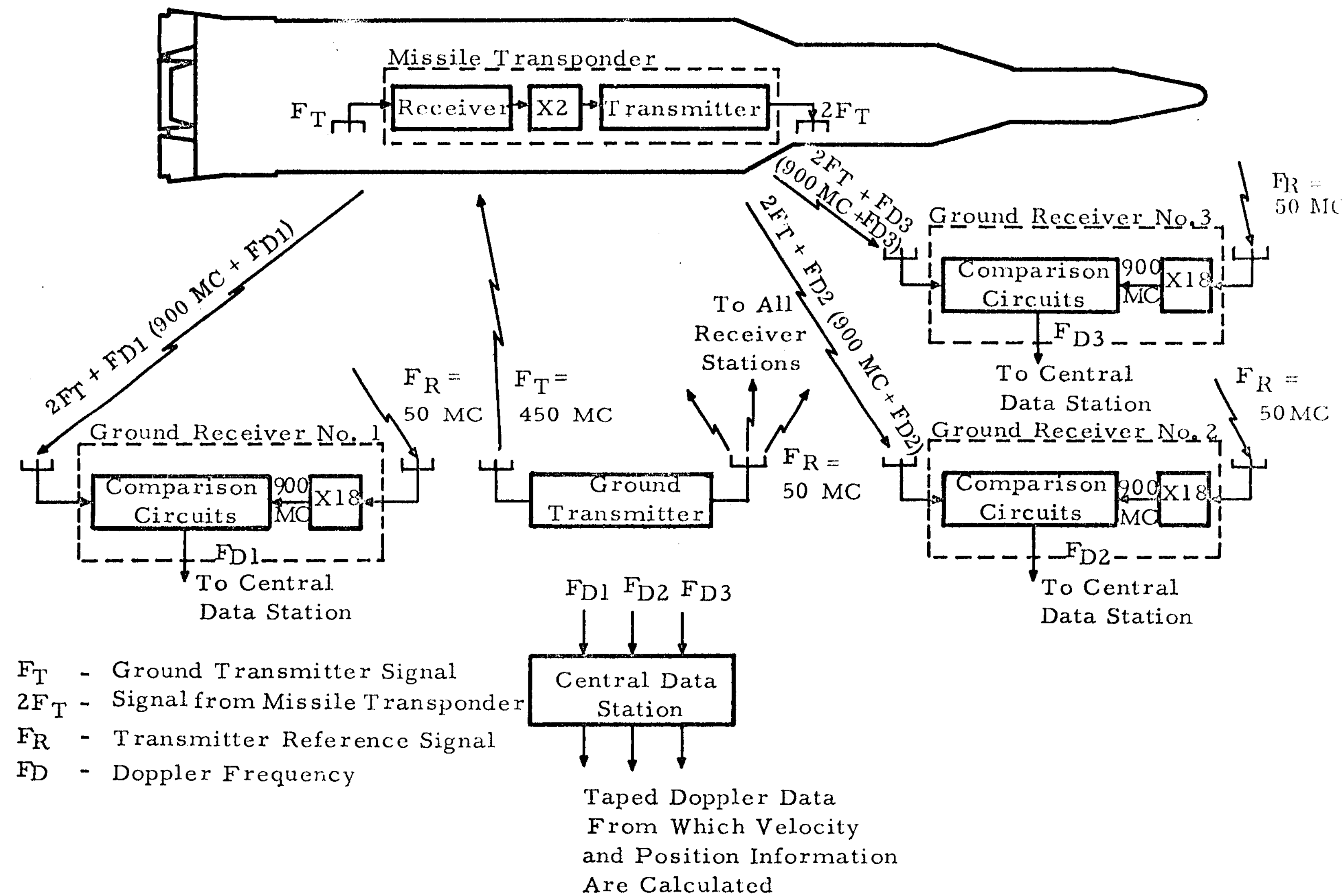


Figure 4-14. UHF Doppler and Position Measuring System (UDOP)

Each UDOP receiving site has an FM data transmitter and communications equipment. No Doppler data recording is done at these sites at the present time, although uncalibrated signal strength strip charts are made. The Doppler data are transmitted in real time to the Central Recording Station, located in Hangar D, which has all the facilities to properly record these data and accurately reference them to range time. The signals are recorded on Ampex tape recorders at a speed of 30 inches per second.

CHECKOUT PHILOSOPHY

Airborne Transponder

The UDOP transponder is relatively trouble free. No maintenance, as such, is performed on the transponder. Faulty units are replaced by spare units on hand. Upon arrival at the launch pad, the transponder is removed and checked out on the bench. Standard commercial test equipment, plus specialized equipment designed and fabricated at LOC, is used to perform the following measurements on the transponder and antenna:

a. Power in versus power out.
b. AGC voltage versus power in.
c. Output frequency.
d. Input frequency.
e. Antenna VSWR.

These measurements establish the performance level of the transponder. The transponder is then re-installed in the vehicle. From this time until launch it is never disconnected or removed, except in the case of major failure.

Throughout the period of launch preparation, the performance of the transponder is assessed by applying power to it, interrogating it, and monitoring the radiated signal with the UDOP ground receivers. The measurements made on the transponder during the bench test are used to form an historical base upon which to evaluate its present performance.

Open-loop checks are also made with all other RF and telemetry systems aboard the vehicle radiating to determine mutual compatibility and absence of interference.

UDOP Ground Stations

The UDOP ground system is continuously manned, maintained, checked out, and calibrated. The VSWR of all antennas are checked once each week. In addition, prior to simulated flight tests or actual launches, the frequency response and sensitivity of all receivers are first checked with a signal generator and then checked with the test transmitter. The output of the receivers is fed to the Central Recording Station over the data link and recorded. The frequency of the test transmitter is varied to simulate Doppler shift. Accurate records of the receiver performance are kept so that any degradation or trend is immediately noted. The normal voice communication network is also checked. Prior to static firing or launch, a detailed countdown procedure is employed to insure that the entire system is in an operational condition.

FUTURE PLANNING

SA-1 and SA-2 were equipped with a modified Gilfillan Bros., Inc., AN/DRN-7 transponder; SA-3 through SA-6 will use the Motorola AN/DRN-11 transponder, but no major change in checkout procedure is anticipated.

Beginning with SA-3 the "Interim Offset UDOP System" will be used. In this mode of operation, the Doppler beat is biased from 0 cps to approximately 1 kc. This type of operation allows the use of data transmission systems which do not need d-c responses and allows the use of a direct record mode of tape recording. The data reduction is much simplified, since tracking filters operate independently from approximately 1 kc through the maximum frequency of Doppler shift.

Starting with SA-6, the JTL transponder, using the full offset system, will be in operation. This system operates with an interrogating frequency of 890 Mc and a return frequency of 960 Mc. The merit in this method of operation is a reduction of radio frequency refraction effects in the interrogator signal transmission path.

C-BAND BEACON

C-BAND RADAR

The AN/FPS-16 radar (Figure 4-15) and its derivatives, manufactured by RCA, is a major source of trajectory measurement data on all the national ranges. The National Aeronautics and Space Administration also operates FPS-16 radars at Bermuda and Wallops Island.

System Description

The AN/FPS-16 is a C-band monopulse radar utilizing a waveguide hybrid-labyrinth comparator to develop angle track information. The comparator receives RF signals from an array of four feed horns which are located at the focal point of a 12-foot parabolic reflector. The comparator performs vector addition and subtraction of the energy received by each horn. The elevation tracking data is generated in the comparator as the difference between the sums of the top two horns. The azimuth tracking error is the difference between the sums of the two vertical horn pairs. The vectorial sums of all four horns is combined in a third channel. Three mixers with a common local oscillator, and three 30-Mc IF strips are used; one each for the azimuth, elevation, and sum signals.

The same four-horn cluster is used for RF transmission. The transmitter output is delivered to the comparator labyrinth, which now acts to divide the outgoing power equally between all four horns. The receivers are protected by TR tubes during the transmit time.

The horn cluster is located approximately at the focal point of a 12-foot parabolic reflector. During the transmission cycle, the energy is distributed equally among the four horns. During the receive cycle, the outputs of the elevation and azimuth comparator arms represent the amount of angular displacement between the target position and electrical axis. Consider an off-axis target; the image is displaced from the focal point, and the difference in signal intensity at the face of the horns is indicative of angular displacement. An on-target condition will cause equal and in-phase signals at each of the four horns and zero output from the elevation and azimuth arms.

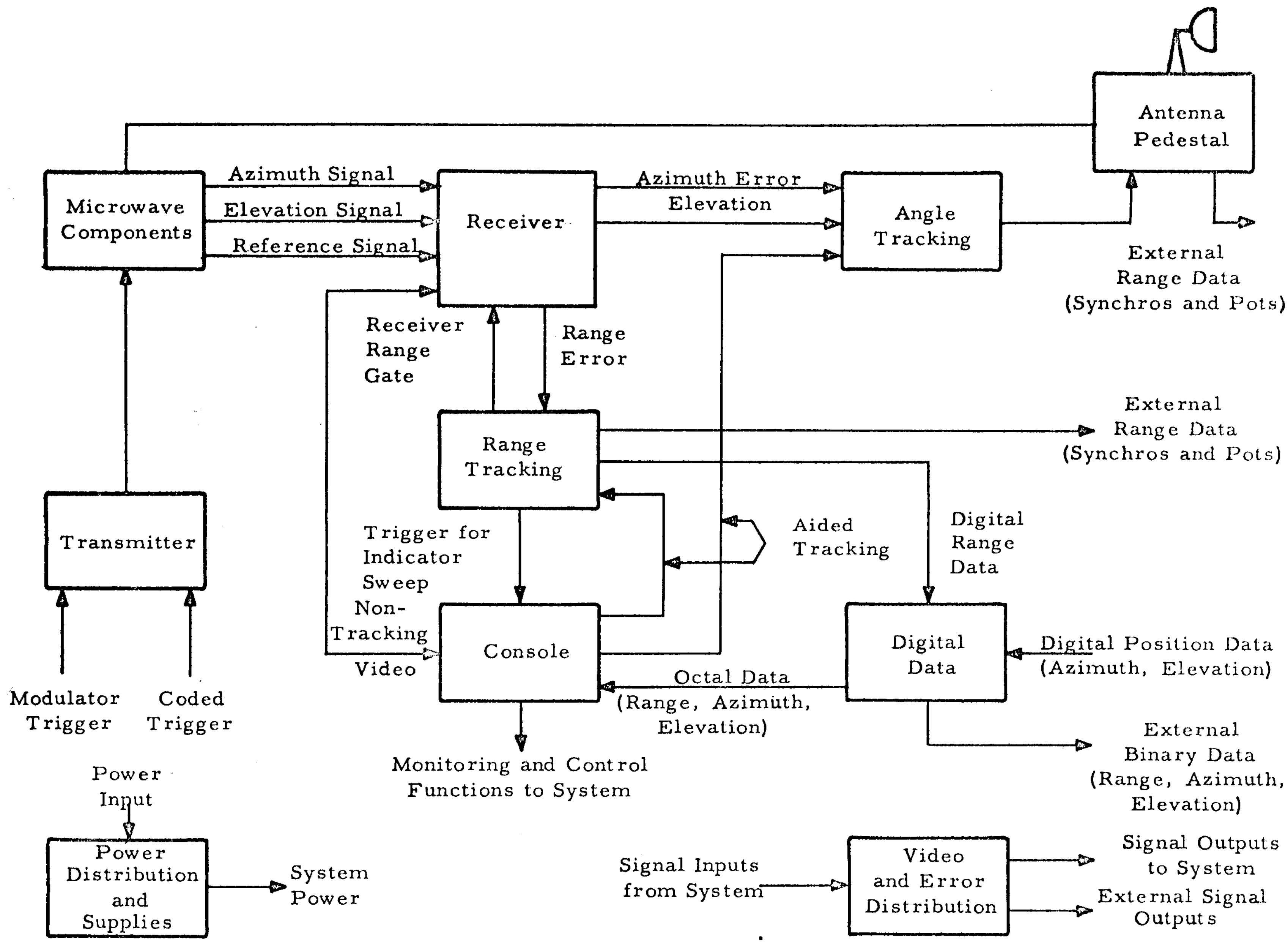


Figure 4-15. Radar Set AN/FPS-16

The sum, azimuth, and elevation signals are converted to 30-Mc IF signals and amplified. The phases of the elevation and azimuth signals are then compared with the sum signal to determine error polarity. These errors are detected, commutated, amplified, and used to control the antenna-positioning servos. A part of the reference signal is detected and used as a video range tracking signal and as the video scope display.

A highly precise antenna mount is required to maintain the accuracy of the angle system. The FPS-16 antenna pedestal is a precision-machined item which is engineered to close tolerances and is assembled in dust-free, air-conditioned rooms to prevent warping during mechanical assembly. The pedestal is mounted on a reinforced concrete tower to provide mechanical rigidity. The electronic equipment is mounted in a two-story concrete building, which also surrounds the tower to decrease tower warpage due to solar radiation.

The radar utilizes a 12-foot parabolic antenna giving a beamwidth of 1.2 degrees at the half-power points. The range system utilizes either a 1.0-, 0.5-, or 0.25-microsecond pulse and the prf can be set by pushbuttons. Twelve repetition frequencies between 341 and 1707 pulses per second can be selected. A jack is provided through which the modulator can be pulsed by an external source. By means of external modulation, a code of from 1 to 5 pulses may be used.

Data take-offs are provided for potentiometer, synchro, and digital information in all three coordinates. The azimuth and elevation digital data is derived from optical-type analog-to-digital encoders. Two geared coders with ambiguity resolution are used for each parameter. The data for each angle is a Gray code 17-bit word in serial form. The overlapping ambiguity bits are removed, and the data is transformed from cyclic Gray code to straight binary before recording or transmission to the computer. The range servo presents a 20-bit straight binary word in serial form after ambiguity resolution and code conversion. The same type optical encoders are used.

The AN/FPS-16 antenna pedestal is mounted on a 12-foot by 12-foot concrete tower which extends 27 feet above grade level. The center of the emplaced antenna is approximately 36 feet above grade level. The electronic equipment, auxiliary system, maintenance section, etc., are housed in a 66-foot by 30-foot by 24-foot two-story concrete block building. The building surrounds, but is not attached to, the pedestal tower. This method of construction places the tower within the air conditioned environment of the equipment building and provides protection from solar radiation and other weather effects which would dilute the inherent accuracy of the system. Power requirements for each station are: 120/208 volts, ±10 volts, 4-wire, 60-cps; 175 kva.

Models of the AN/FPS-16

AN/FPS-16 (XN-1)

The first experimental model was made with an X-band RF system and a lens-type antenna. It later was changed to C-band with a reflector antenna. This radar was further modified for use on Vanguard and is now in use at the Atlantic Missile Range, Patrick AFB, Florida.

AN/FPS-16 (XN-2)

Two of this model were made. One was installed on Grand Bahama Island, BWI, for the Vanguard program, and one remains at RCA, Moorestown, N. J. These radars are almost identical to later production models.

AN/FPS-16 (XN-3)

This is an experimental version of AN/FPS-16 (XN-2) that includes a 3-megawatt modification kit, a circular polarization kit, a data correction kit, and a boresight television kit. This radar is at RCA, Moorestown, N. J.

AN/FPS-16AX

This is a production AN/FPS-16 modified according to (XN-3) above. Three radars located at White Sands Missile Range, and one located at Moorestown, New Jersey, have been so modified. AN/MPS-25 is the nomenclature of a trailer-mounted production model AN/FPS-16.

AN/FPQ-4

This is an adaptation of AN/FPS-16 that was made for use as a target tracker in the land-based Talos system. Two models were installed at WSMR. Two more models, with modifications, were installed on a ship for use in the Atlantic Missile Range on the DAMP program. A fifth such radar is at RCA, Moorestown, N. J. as a part of the DAMP research facility.

Electrical Characteristics for AN/FPS-16

The electrical characteristics of the AN/FPS-16 are listed below.

a. Transmitter

Nominal power output	1 megawatt peak (fixed-frequency magnetron) 250 kw peak (tunable magnetron)
Frequency	5840 ±30 Mc fixed 5450 to 5825 Mc tunable
PRF (internal)	341, 366, 394, 467, 569, 682, 732, 853, 1024, 1280, 1364, or 1707 pps
Pulse widths	0.25, 0.50, 1.0 μsec
Code groups	5 pulses, maximum, within 0.001 duty cycle limitation of transmitter

b. Radar Receivers

Noise figure	11 db
Intermediate frequency	30 Mc
Wide bandwidth	8 Mc
Narrow bandwidth	2 Mc
Dynamic range of gain control	93 db
Gate width of tracking and acquisition	
Tracking	0.5 μsec 0.75 μsec 1.25 μsec
Acquisition	1.0 μsec 1.25 μsec 1.75 μsec

c. Coverage

Range	500 to 400,000 yds
Azimuth	360 degrees, continuous
Elevation	-10 to +190 degrees

d. Data Outputs --- Digital (Binary)

(Range, azimuth and elevation position information))	Synchro (dual speed) Potentiometer

e. Servo Bandwidth

Range	1 to 10 cps (variable)
Angle	0.25 to 5 cps (variable)

Type of presentation	Dual-trace cathod-ray tube, A/R and R type displays
Accuracy	
Range	5 yds
Angle	0.1 mil

TECHNICAL DESCRIPTION - C-BAND BEACON

The C-band transponder operates in conjunction with ground pulse radar systems to provide trajectory data for range safety and post-flight analyses. The C-band components carried on board the vehicle are the Model AN/DPN-55 transponder and the Model 703 antenna.

The transponder is interrogated by a ground based pulse radar system. The transmitter is triggered by the interrogate pulse causing a response pulse which is received by the ground radar and used to measure vehicle position and velocity. Interrogate and response pulses are duplexed on the same antenna system. The trajectory data is used for range safety back-up and post-flight analysis as well as for primary vehicle tracking.

Electrical Characteristics for AN/DPN-55 Beacon

Frequency range	5400 to 5900 Mc
Stability	±4 Mc
IF frequency	50 Mc
Receiver sensitivity	-65 dbm
Receiver bandwidth	8 Mc (minimum)
Transmitter pulse width	$0.7 \pm 0.2\ \mu$sec
Interrogation rate	200 to 1000 pps
Pulse rise time	$0.1\ \mu$sec (maximum)
Pulse delay	$1.0\ \mu$sec (maximum)
Peak power output	400 w (minimum)
Supply voltage	28 vdc nominal
Operating range	26.5 to 29.5 vdc
Supply current	2.9 amperes

CHECKOUT PHILOSOPHY

The equipment is installed in the vehicle prior to arrival at the launch site. It has been checked in great detail, prior to shipment. System checks are performed, first on a closed-loop basis and then open-loop. Faulty units are replaced by spares as necessary. No repairs are performed but causes of difficulty are determined. The antenna system is checked out and the VSWR measured. System compatibility is measured and RF interference checks performed by the range are monitored. No radical changes in approach are anticipated for the future.

CHECKOUT TESTS

The following checks are made on the C-Band Beacon.

Prior to Erection of the Vehicle on the Complex

a. Measure attenuation and VSWR of the checkout cable from the RF room in the structure to platform No. 1.
b. Verify operation of the checkout and monitor equipment in the structure and in the Launch Control Center.

Closed-Loop and Range Checkout of the Beacon

a. Connect equipment as in Figure 4-16.
b. Measure and record the parameters indicated on the test sheet (Figure 4-17).
c. Reconnect the beacon for open-loop operation.
d. Arrange for range radar to check the beacon. Monitor this check.

RF Instrumentation Test

a. Verify that the beacon is connected for open-loop operation.
b. Monitor operation of the beacon during the tests.
c. Obtain the readout of beacon parameters (Figure 4-18) and evaluate beacon performance.

OAT No. 3 and No. 4

a. Connect the beacon for closed-loop operation.
b. Measure beacon performance.

SFT

a. Verify that the beacon is connected for open-loop operation.
b. Monitor beacon performance during the test.
c. Obtain the readout of beacon parameters and evaluate beacon performance.

Launch Countdown

a. Visually inspect the transponder and associated cables.

b. Monitor transponder operation during range checks.

c. Obtain readout of beacon parameters and evaluate beacon performance.

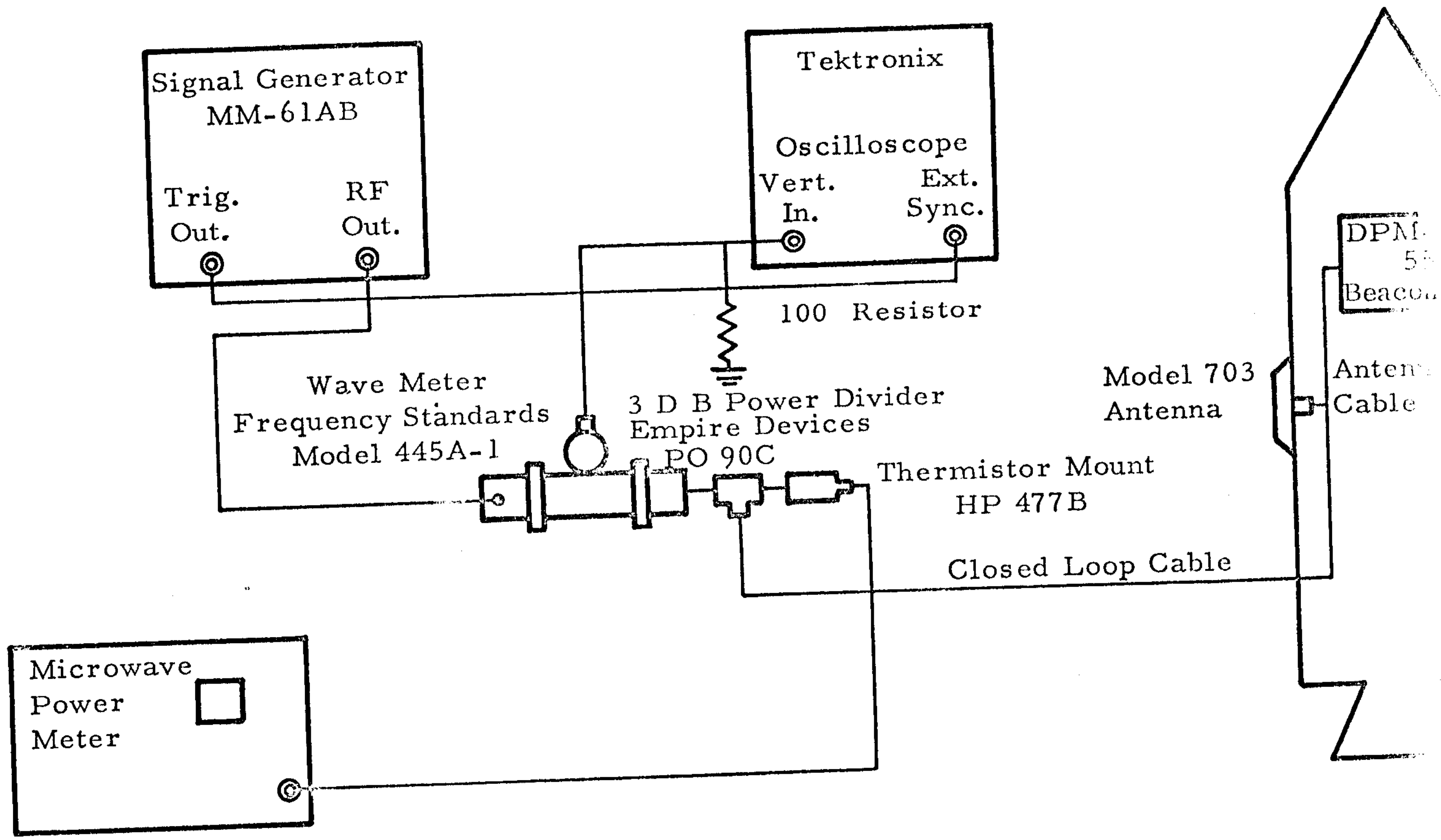


Figure 4-16. Closed-Loop Checkout for C-Band of Action

RADAR BEACON - BENCH CHECK

Date: ____________________

Missile: ____________________

Type: ____________________ Serial No. ____________________

Frequency-Receiver ____________________ Mc

Frequency-Transmitter ____________________ Mc

Signal Delay ____________________ m/sec

Pulse Width ____________________ m/sec

Sensitivity ____________________ dbm

Power ____________________ watts at ____________ db

Voltage Readings

Transmitter __________ v __________ ma

__________ v __________ ma Filament __________ v

__________ v __________ ma Filament __________ v

Receiver __________ v __________ ma

__________ v __________ ma

Input Voltage __________ v

Antenna

Type: __________

Location: __________ inches from fin __________ toward fin __________

Figure 4-17. Radar Beacon - Bench Check

RADAR BEACON EVALUATION

Test No. ____________________

Date ____________________

Missile ____________________

Type ____________________ Serial No. ________________________

	Check No.	Check No.	Check No.	Check No.
Radar				
Frequency-Interrogation				
Frequency-Beacon Transmitter				
Radar Range				
Radar to Pad - Survey				
Signal Delay				
Pulse Width				
Countdown				
Jitter				
Beacon Recovery				
Signal Strength				
Balance				
Time				
Go - No Go				
Blockhouse Measurements				
Beacon Frequency				
Frequency FPS-16/XN-1				
Signal Strength - Beacon				
Signal Strength - Radar				

REMARKS:

Figure 4-18. Radar Beacon Evaluation Sheet

COMMAND RECEIVER

The main purpose of the range safety command destruct system is to provide a positive means of terminating the vehicle flight upon command from the ground.

To fulfill range safety requirements, two AN/DRW-13 command receivers are aboard each missile fired on the Atlantic Missile Range.

TECHNICAL DESCRIPTION

The AN/DRW-13 command set consists of a UHF receiver and a 10-channel audio decoder with associated relays (Figure 4-19). The ground transmitter sends a tone combination which is coded to actuate a particular relay. Only two channels are used on the S-I Stage for engine cutoff and destruct. A single tone combination is used for the cutoff sequence and to arm the destruct system. The second tone combination initiates the destruct action.

Technical specification for the AN/DRW-13 are as follows:

Weight (receiver and power supply)	2 3/4 pounds
Volume	39 in^3
Power consumption	7 watts
Frequency range	405 to 420 Mc
Minimum sensitivity (6 channels)	5 microvolts

CHECKOUT PHILOSOPHY

The philosophy on checkout is similar to that of the C-Band Beacon. No changes are anticipated for future requirements.

CHECKOUT TESTS

The following checks are performed on the Command Receiver.

Prior to Closed-Loop Tests

a. Measure the attenuation of the checkout cable (refer to "Checkout Procedures and Test Records for Command Receiver AN/DRW-13," page 84-85).

b. Verify the calibration of the test equipment required on page 84 of the checkout procedures. Refer to the manufacturer's instruction manuals for calibration instructions.

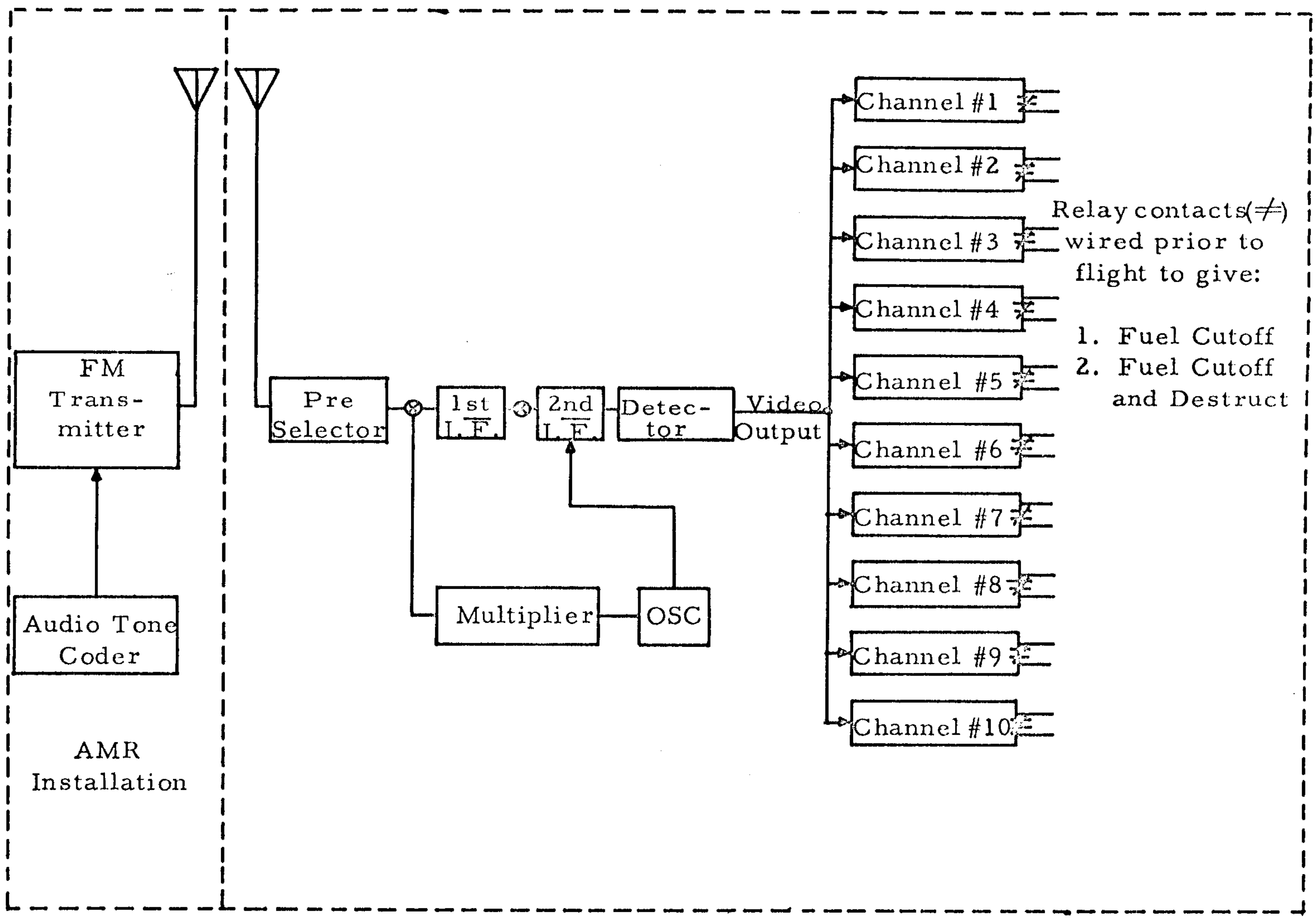


Figure 4-19. Range Safety Command System AN/DRW-13

Closed-Loop Checkout

a. Check out the vehicle receivers as described in Checkout Procedures and Test Records for Command Receiver AN/DRW-13.
b. Check out the spare command receiver at the LCC using the same procedures used in the checkout of the vehicle receivers. Substitute an attenuator for the closed-loop cable attenuation.
c. Assist the on-board telemetry personnel in the measurements of antenna system SWR and attenuation.
d. Arrange for an open-loop test, using the range command transmitter. Request the range to send all command functions and verify correct operation of vehicle command receivers.

RF Instrumentation Tests

a. Verify that the command receivers are connected for open-loop operation.
b. Monitor the operation of the receivers during both instrumentation tests. Report any interference observed during the tests.

OAT No. 1 and No. 2

a. Connect the vehicle receivers for closed-loop operation. Transmit command functions as required during the test.
b. After termination of OAT, reconnect the command receivers for open-loop operation.

OAT No. 3 and No. 4

a. Verify that the receivers are connected for open-loop operation.
b. Monitor the operation of the receivers during the tests and report any interference or irregularities.

SFT

a. Prior to the start of test, measure threshold sensitivity of both receivers as described on page 85 of Checkout Procedures.
b. Reconnect the receivers for open-loop operation.
c. Monitor the operation of the receivers during the SFT and report any interference or unsatisfactory condition.

Launch Countdown

a. Visually verify that the command receivers and antenna system are connected for flight.
b. Monitor the operation of the receivers during the range checks.

SECTION 5

C-1 BLOCK II EQUIPMENT

RADAR ALTIMETER

TECHNICAL DESCRIPTION

The radar altimeter is to be used to provide more nearly continuous altitude information during periods in which land-based tracking systems are unable to provide data. The system to be used is a pulsed radar with an altitude capability of 50 km to 400 km. The total path time of the radar signal to the sea and back to the vehicle is measured very accurately by means of a stable crystal oscillator and a counting system. This path time is directly related to vehicle altitude. It is digitally encoded for telemetering to the ground or for recording on tape for later playback as the vehicle comes within range of a tracking station.

The counting circuit is started by the transient pulse and stopped by the received pulse. During the counting interval, cycles of the stable oscillator frequency are counted and converted to a digital readout of range. Through feedback networks which provide a memory capability, a receiver gate is positioned at the expected return position. This results in an effective gain of sensitivity for the system. A system block diagram is shown in Figure 5-1.

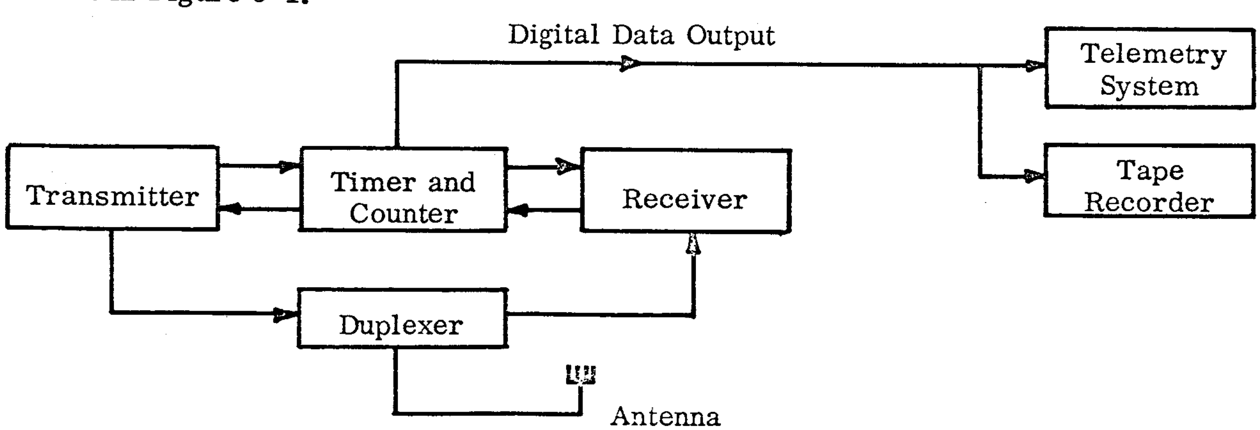


Figure 5-1. System Block Diagram

A developmental model of the altimeter is expected to be incorporated in the SA-4 vehicle.

DESIGN SPECIFICATION (PRELIMINARY)

a. Over-all Package

Weight	25.1
Dimensions	13.25" x 9.88" x 9.06"
Input power	80 w maximum, 28 vdc

b. Transmitter

Type	Re-entrant cavity and triode
Frequency	1610 Mc
Peak power	5 kw minimum
Pulse width	0.8 μsec to 1.1 μsec
PRF	144 pps

c. Receiver

Type	Heterodyne with 1N21E crystal mixer
Noise figure	8 db
IF bandwidth	2.5 Mc
IF frequency	30 Mc
Video bandwidth	625 kc
Detector type	Square law
Automatic features	AGC

d. Start Pulse Detector

Type	Crystal video
Amplifier bandwidth	8 Mc

e. Counter Gate Generator

Type	Tracking range gate
Inputs required	(1) Start pulse (2) Video amplifier pulse
Outputs (internal)	(1) Rectangular gate (2) Gated video for AGC

f. Clock Synchronizer and Readout

Type	Gated binary counter
Clock	21.233664-Mc crystal oscillator
Stability	1 part in 10^6
Outputs to telemetering	(1) Altitude (2) Elapsed time (3) Inhibit signal

Readout rate	36/sec
Data increment	Approximately 24 ft

g. Performance

Altitude capability	50 km to 400 km over the sea
Attitude capability	(1) ±11 degrees pitch relative to mean pitch angle (2) ±10 degrees roll relative to mean roll angle
Vertical Velocity Capability	
Climbing trajectory	6 km/sec at 50 km
Horizontal trajectory	1 km/sec

h. Summary of Outputs to Telemetering

Altitude	18-bit binary word
Elapsed time	9-bit binary word
Inhibit signal	5 vdc, 4800 μsec pulse, between "reset" and "clear"
Reliability signal	5 vdc signal present for "locked operation"
Voltage level of "0" in binary word	0 to 0.5 vdc
Voltage level of "1" in binary word	4.5 to 5.5 vdc

CHECKOUT TESTS

In general, the radar altimeter can be checked with standard commercial test equipment. The altimeter is checked on the bench at MSFC prior to installation in the vehicle. A special hat has been designed and fabricated at MSFC to permit checkout of the altimeter in the vehicle using the altimeter antenna system.

Tests performed on the radar altimeter are as follows:

a. Clock frequency
b. Power output
c. Accuracy and jitter
d. Minimum discernible signal
e. Measurement tests

The radar altimeter can be exercised from the blockhouse using the test setup indicated in Figure 5-2. Using this method the proper function of the altimeter can be checked from the blockhouse by varying the echo return.

Telemetered altitude information should be equal to equivalent altitude delay introduced plus measured fixed delay at the test setup. This should be checked at low and high simulated altitudes. The accuracy of the altimeter output should be ±100 feet.

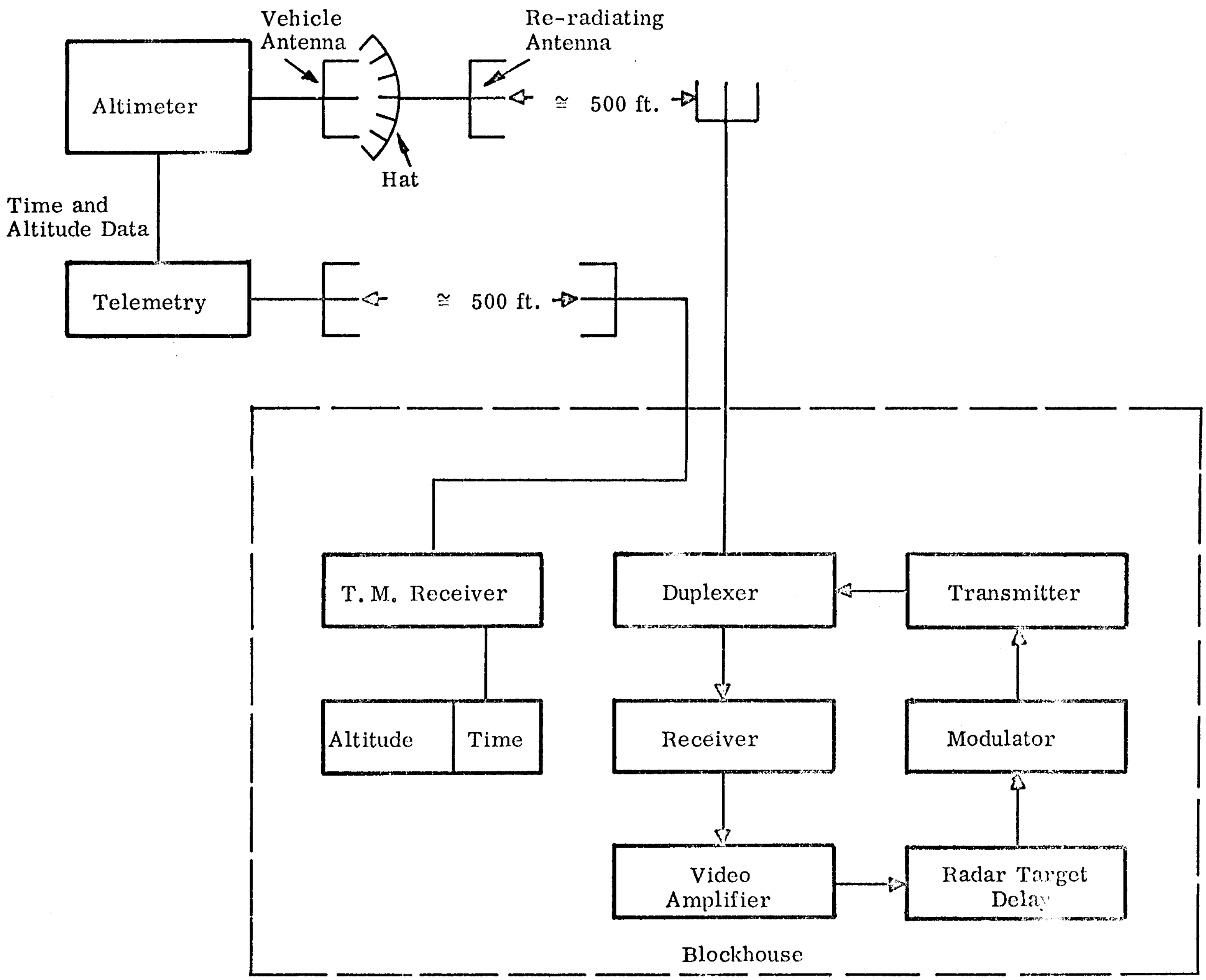


Figure 5-2. Radar Altimeter Test Setup

DIGITAL COMMAND SYSTEMS

RANGE SAFETY SYSTEM

Two problem areas exist with the present range safety system; a lack of sufficient communications security and a limitation to the number of commands that can be transmitted. The number of functions possible is limited to 17. For these reasons, a development program for a digital range safety system is underway. Modifications to the present command transmitter will permit the encoding of the vehicle address and the vehicle command. The on-board equipment will compare the address sent with that assigned the vehicle before the command is executed. Any difference in address will cause the vehicle to ignore the command. Sample figures clearly illustrate the improvements that can be obtained with this system. A 15-bit code for address or command will yield 32, 768 possible combinations. The increase in security and flexibility will be achieved with the introduction of the digital equipment in the Saturn program on SA-9, if not before. A system block diagram is shown in Figure 5-3.

FLIGHT PATH CORRECTION SYSTEM

Injection techniques of today, relying on inertial guidance systems, are not accurate enough for the requirements of the Apollo program. Trajectory corrections will have to be made after vehicle injection. A digital flight path correction system is planned for use on SA-6. A block diagram of this system is shown in Figure 5-4.

The command system will function as follows: the digital coder will be used to select the proper address for a given message and to translate trajectory correction data into the proper form for transmission. The transmitter will radiate an RF carrier containing the data in the form of superimposed modulation in either of two states representing ones or zeros. Various methods of modulation may be used and the selection of a particular type would be governed primarily by security considerations and by efficient utilization of the RF bandwidth.

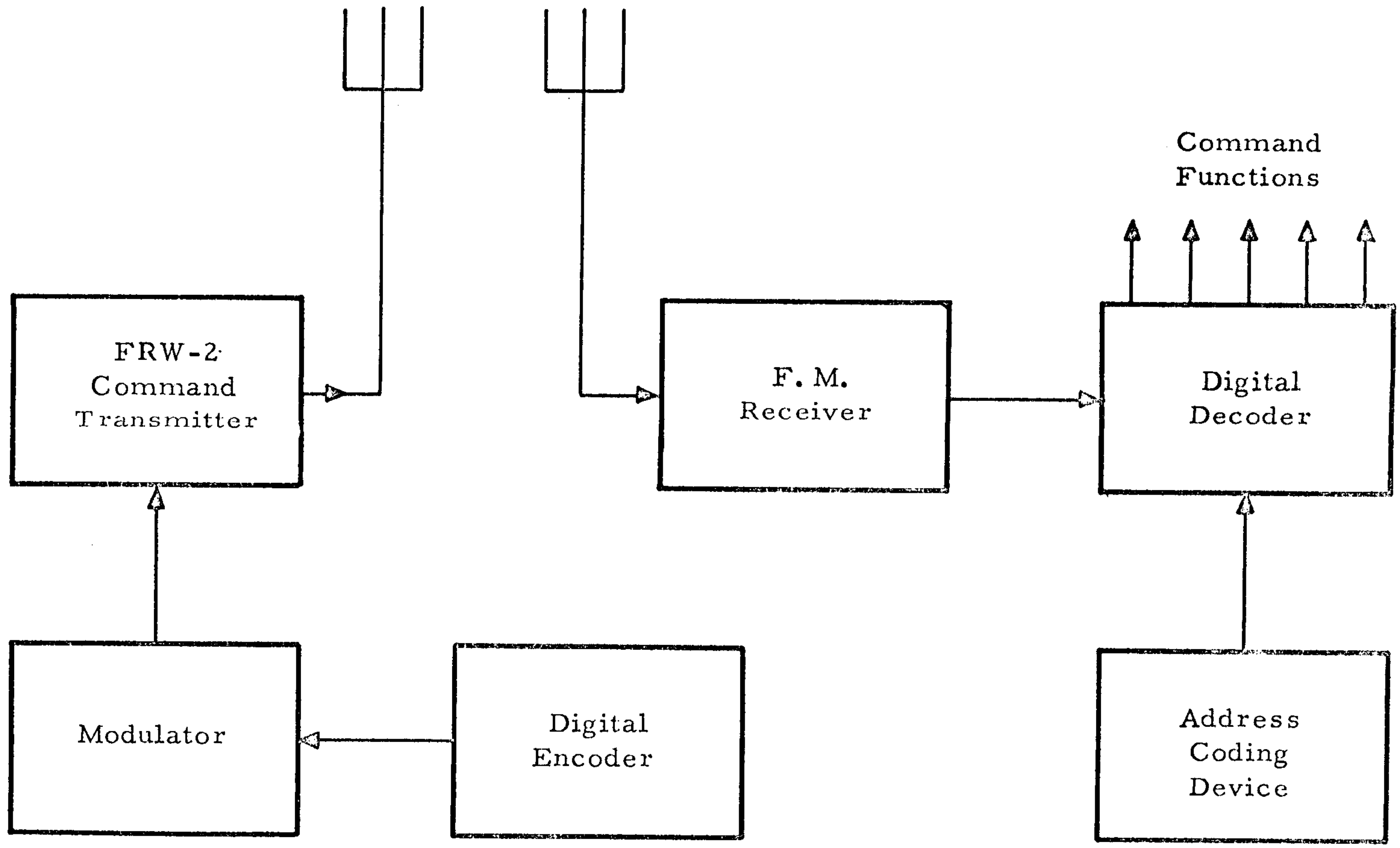


Figure 5-3. Digital Range Safety System

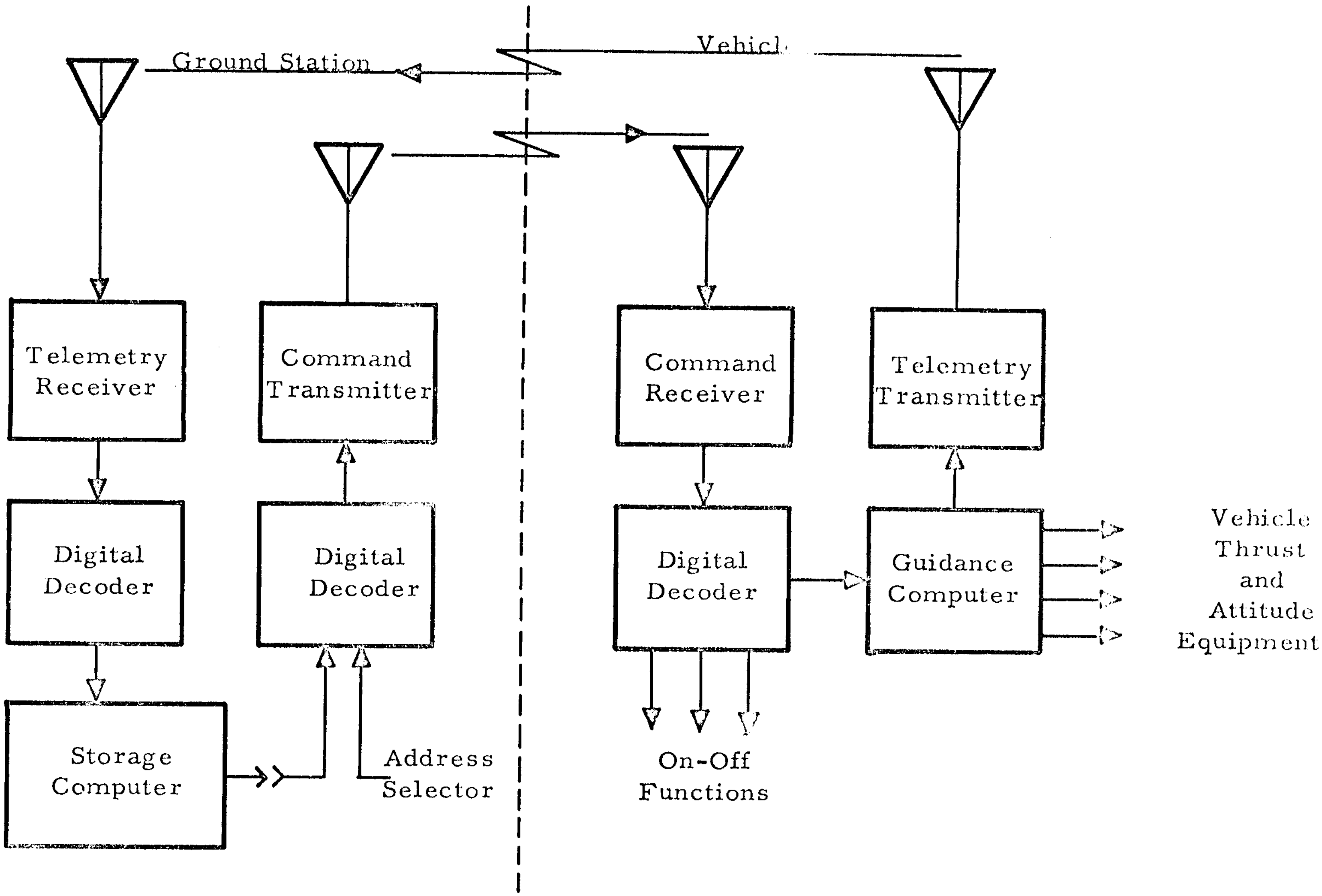


Figure 5-4. Digital Flight Path Correction System

On-board the vehicle, the command receiver demodulates the carrier and presents the digital information to the decoder. The decoder separates the information and channels it to the desired function as determined by the address or addresses included in the message. The address may be injected into the command message in various ways. For example, the address may precede the command word or may be scattered in random fashion through the message structure.

In case of vernier trajectory correction data, the information will be directed into the guidance computer for storage. This guidance computer is an integral part of the Saturn inertial guidance system. The transmission clock rate, which will be variable, will be determined by bandwidth requirements prior to launching of the vehicle.

An important feature of the command system will be the ability to store data in the guidance computer for execution at a future time or for execution upon command. This feature makes it possible to calculate a required velocity change (plus or minus) or orientation change to take place at time X and then transmit the necessary command information at X - h hours as the vehicle is passing near a command station.

The telemetry link of this system will be used to compare the data stored in the guidance computer with the original message transmitted. Upon transmission of the appropriate ON-OFF command, the data stored in the guidance computer can be scanned and retransmitted to the ground station for verification prior to execution.

Tracking stations will accumulate data during the early portions of the flight to determine the trajectory error. These data will be analyzed to determine the corrections required. The corrections will then be transmitted in digital form to the on-board guidance computer for storage and execution.

CHECKOUT OF DIGITAL COMMAND SYSTEMS

No documented procedures are available at the present time, but it is anticipated that procedures similar to those used for other RF equipment will be used. The response to digital commands will be monitored, probably closed-loop to maintain secure transmission. Receiver sensitivity and antenna VSWR will be measured. The system approach toward testing will continue to be used.

AROD TRACKING SYSTEM

INTRODUCTION

The AROD tracking system is under study as a solution to the problem of obtaining trajectory information for those portions of the Saturn flight path which are beyond the radar horizon for the land-based tracking system. The AROD system lends itself to shipboard application because it is an "upside-down" system. That is to say, the transmitter is vehicle-borne and the transponders are earth-bound. Thus it minimizes the complexity of the shipborne installation, but does so by increasing the complexity of vehicle equipment.

In order to successfully use any shipborne system, the geodetic position of the moving platform must be continuously and precisely known. In addition, a system which triangulates from two or more shipborne platforms requires a precise knowledge of the spatial relationship of the platforms to each other. In the AROD system it is expected that Loran C will fulfill these requirements.

GENERAL DESCRIPTION OF SYSTEM

The proposed system is a three-coordinate Doppler tracking system that differs from the existing Doppler systems in two principal characteristics. First, the system is inverted in the sense that it is proposed to locate the transmitter and receivers on board the vehicle with the transponders at the ground stations; and second, two frequencies are transmitted at all times to each ground station in order to obtain unambiguous range without the necessity of integrating the Doppler cycles. One frequency is constant, and the other is phase modulated sequentially with several frequencies or with continuous frequency variation. (There are variations of this ambiguity-resolving scheme that may finally be preferred.)

System Advantages

The advantages of the proposed system are in the areas of accuracy and data handling and reduction, elimination of communications and timing problems.

Accuracy

In considering the system accuracy, frequency instability in the transmitter is no more a problem for this system than for the Doppler systems in use. The signal returned from the transponder is compared with a signal taken from the transmitter so that short-term frequency instability is of primary importance.

By virtue of the fact that the transmitter is located on board the vehicle, the measured range is always from each ground station to the vehicle as opposed to range sum between two ground stations and the vehicle, as frequently obtained in existing Doppler systems. This "range only" measurement yields the best accuracy and simplest data reduction for a given geometry of ground stations.

Data Handling and Reduction

Because the transmitter is on the vehicle and because the ground stations are transponders only, no communication between ground stations is required. The data is measured on the vehicle, and each set of data is collected at one time on the vehicle and transmitted either to the reduction center on one communication link or to the guidance computer and thence to the guidance system on the vehicle. The data reduction time required is greatly improved over existing Doppler systems because "range only" instead of "range sum" is measured to each ground station, thus permitting the simplest possible calculation for a three-coordinate Doppler system.

Since the data is collected on the vehicle, the vehicle timing reference must be used, and the necessity for transmitting time to each ground station with all of the attendant difficulties and errors is eliminated.

Cost

The simplicity of the ground stations makes them readily transportable to practically any part of the world, so that it is not necessary to construct a new set of ground stations for each new firing azimuth. Because of the simplicity of the ground stations, the manpower required will be modest. Perhaps one man per station will be sufficient, and stations located away from normally manned locations may be unattended. The minimum number of communication links is used. Only one link is required between the vehicle and each ground station. An additional telemetry channel from the vehicle to a data reduction station is necessary, or the data may be reduced on the vehicle.

In the proposed system, unambiguous range to each of three stations is measured by transmitting two carrier frequencies from the vehicle to each ground station. At each ground station the received carriers are off-set by a slight amount to new frequencies (different for each ground station). These frequencies are then retransmitted to the vehicle where they are received by three receivers. Hence, in this system one transmitter and three receivers are required on board the vehicle. To make the same measurement using the existing types of Doppler systems requires a transponder on the vehicle for each ground station to which range is to be measured. Thus, three transponders would be required on the vehicle as opposed to the three receivers and one transmitter required for the proposed system. The advantage here is one of size and weight, but mostly of power consumption, since most of the power consumed by the tracking equipment on board the vehicle is used by the transmitter or transmitting portion of the transponders.

A portion of the receiver is required on the vehicle for each coordinate to measure. This requirement may be reduced by using a broad-band RF amplifier and converting to an IF for each frequency. If, however, sensitivity is important, a narrow-band RF amplifier should be used for each frequency. This can be done and still maintain small size and low power requirements if solid-state "tunnel diode" amplifiers, or parametric amplifiers are used.

An additional telemetry channel is required on the vehicle to transmit the Doppler data to the reduction center.

Equipment Specifications

The large-scale system parameters are tabulated below. These were obtained from consideration of the state of the art, the environmental requirements, and cost.

Vehicle Equipment

Transmitter Frequencies	2 KMc (approx.) 2.02 KMc phase modulated
Transmitter Power Output	5 watts nominal 25 watts for extended range
Transmitting/Receiving Antenna Gain	3 db nominal 20 db for extended range
Receiver Input Noise Figure	2 db (paramp. preamp.)
Receiver Bandwidth	120-cps phase-locked with auto-acquisition capability
Receiver Input Signal/Noise	20 db

Ground Station Equipment

Transponder Frequencies	2.6 KMc (approx.) 2.62 KMc
Transmitter Power Output	5 watts nominal 25 watts for extended range
Transmitting/Receiving Antenna Gain	3 db nominal 20 db for extended range
Receiver Input Noise Figure	2 db (paramp. preamp.)
Receiver Bandwidth	120-cps phase-locked with auto-acquisition capability

Using these parameters, the maximum radio ranges can be computed. These are:

$$R_{mx} = 4300 \text{ km nominal}$$

$$= 640,000 \text{ km for extended range}$$

Expected Performance

Range Accuracy	10 ft
Ambiguity Resolution	0.1 ft
Incremental Range Resolution	0.1 ft
Velocity Accuracy (above or below ionosphere)	0.15 ft/sec
Velocity Accuracy (in ionosphere)	0.2 ft/sec
Incremental Velocity Resolution	0.1 ft/sec

MISSILE TRAJECTORY MEASUREMENT SYSTEM (MISTRAM)

INTRODUCTION

MISTRAM has just been installed at Valkaria, about 30 miles south of Cape Canaveral. It consists of two L-shaped baselines with antennas spaced at 10, 000 and 100, 000 feet. By using the 10, 000-foot baseline, measurements of range, range rate, range difference and range-difference rates may be made. The 100, 000-foot baseline is also used for range difference and range-difference rate measurements. The system will use an X-band ground transmitter which will transmit two frequencies, spaced approximately 256 megacycles apart. One of these frequencies is swept in frequency by 8 megacycles. The airborne transponder offsets the retransmitted frequency by 68 megacycles. The 256-megacycle carrier separation is used for fine range measurements and the 8-megacycle sweep is used to resolve ambiguity. Range and angle rate measurements are made on the basic fixed frequency carrier. MISTRAM is expected to produce velocity measurements accurate to 0.1 foot per second for X and Y, and 0.4 foot per second for Z. Later improvements planned for the system are expected to increase the velocity accuracy to 0.05 foot per second in all coordinates.

To date, the MISTRAM system has been installed and the evaluation program is just beginning. Consequently, all references in this report to system performance are based on theoretical calculations, laboratory tests, and analog computer simulations and are not intended to represent verified performance.

SYSTEM DESCRIPTION

Through the use of phase-stabilization techniques, to overcome the deleterious effects of temperature and equipment changes on the electrical length of signal paths between stations, MISTRAM is expected to make precise triangulation measurements over long baselines with an extremely high degree of accuracy.

The two sets of baselines (10K and 100K) produce essentially redundant measurements of the difference quantities. Aside from the desirable features of improved system reliability and enhanced accuracies from such redundancies, the 100K baselines are necessary to obtain the requisite low angular-rate (velocity) errors. This objective is achieved primarily through a reduction in the effects of survey and propagation errors. This baseline length is ten times greater than that required to meet the specified angle (or position) error limits. However, the 10K baselines at the Valkaria site are required for field validation of the techniques to be used for future installations in obtaining precision calibration of the angle data across the 100K air-link baselines. For the Valkaria system, the 100K baselines serve as the primary source of velocity data, and the 10K stations serve as back-up. The 10K baselines, in turn, are the primary source of position data, with the 100K baselines as back-up.

The second MISTRAM is being installed on Eleuthera Island in the Bahamas. Except for relatively minor changes in the central-station equipment to permit passive tracking of the transponder while it is being interrogated by the Valkaria station, the Eleuthera system is identical to the Valkaria station minus the 10K remote stations.

SYSTEM OPERATION

A standard tracking antenna at the MISTRAM central station is used to acquire the missile, track its flight, and transmit signals to the missile beacon. Five receiving antennas, one at the central station and one at each of the remote stations, are slaved to this tracking antenna so that they also follow the vehicle and receive the signals from its beacon.

Determination of the position and velocity of a missile in flight is accomplished in the MISTRAM system by the use of interferometer measurements and triangulation techniques. The position of the vehicle is determined by triangulation techniques involving measurements of range and range difference. The velocity of the vehicle is determined by comparing the rates at which range and range-difference measurements are changing. The total trajectory data available from the Valkaria MISTRAM is range, four range differences, range rate, and four range-difference rates. From the Eleuthera configuration, range, two range differences, range rate, and two range-difference rates are obtained.

Consider the matter of position. Range is determined (at the central station) by measuring the time required for radar signals to travel from the central station to the transponder in the vehicle and back to the central station. From this measurement the range of the vehicle from the central station position is not defined. In other words, it will be known only that the vehicle lies on the surface of an imaginary hemisphere whose center lies at the central station and whose radius is equal to the range (Figure 5-5A).

At the instant of the above measurement, the difference in distance between the vehicle and the central station, and between the vehicle and one of MISTRAM's 10,000-foot remote stations, is measured to obtain a range difference. From this difference measurement it is known that the vehicle, regardless of its range from either station, must lie on the surface of an imaginary hyperboloid whose axis passes through both stations (Figure 5-5B).

At this same instant, the difference in distance between the vehicle and the central station, and between the vehicle and the other 10,000-foot remote station, is measured to obtain a second range difference. From this second difference measurement it is known, as before, that the vehicle must lie on the surface of another imaginary hyperboloid whose axis passes through the central station and this second remote station (Figure 5-5C).

It is now known that the vehicle lies on the surface of both hyperboloids and that the hyperboloids intersect in space; consequently, the vehicle will lie somewhere along this line of intersection. Since the vehicle's range from the central station describes a hemisphere, the intersection of this hemisphere with the hyperbolic intersection is a point which, therefore, defines the vehicle's position in space relative to the ground stations (Figure 5-5D).

Velocity is determined in the MISTRAM system by comparing the rates at which the range and four range differences are changing. Range rate is extracted from the central station range measurement, while range difference rates are extracted from the four range differences, as measured between the central station and each of the four remote stations.

SYSTEM CONCEPT - SUBSYSTEM COMPONENTS

The MISTRAM system is composed of six in-line ground subsystems, plus the airborne transponder, its associated test set, and an auxiliary checkout kit as shown below:

a. Precision Measuring Subsystem
b. Acquisition and Tracking Subsystem
c. Analog Computer Subsystem
d. Communication Link Subsystem
e. Data Multiplex Subsystem
f. Data Transmission and Recording Subsystem

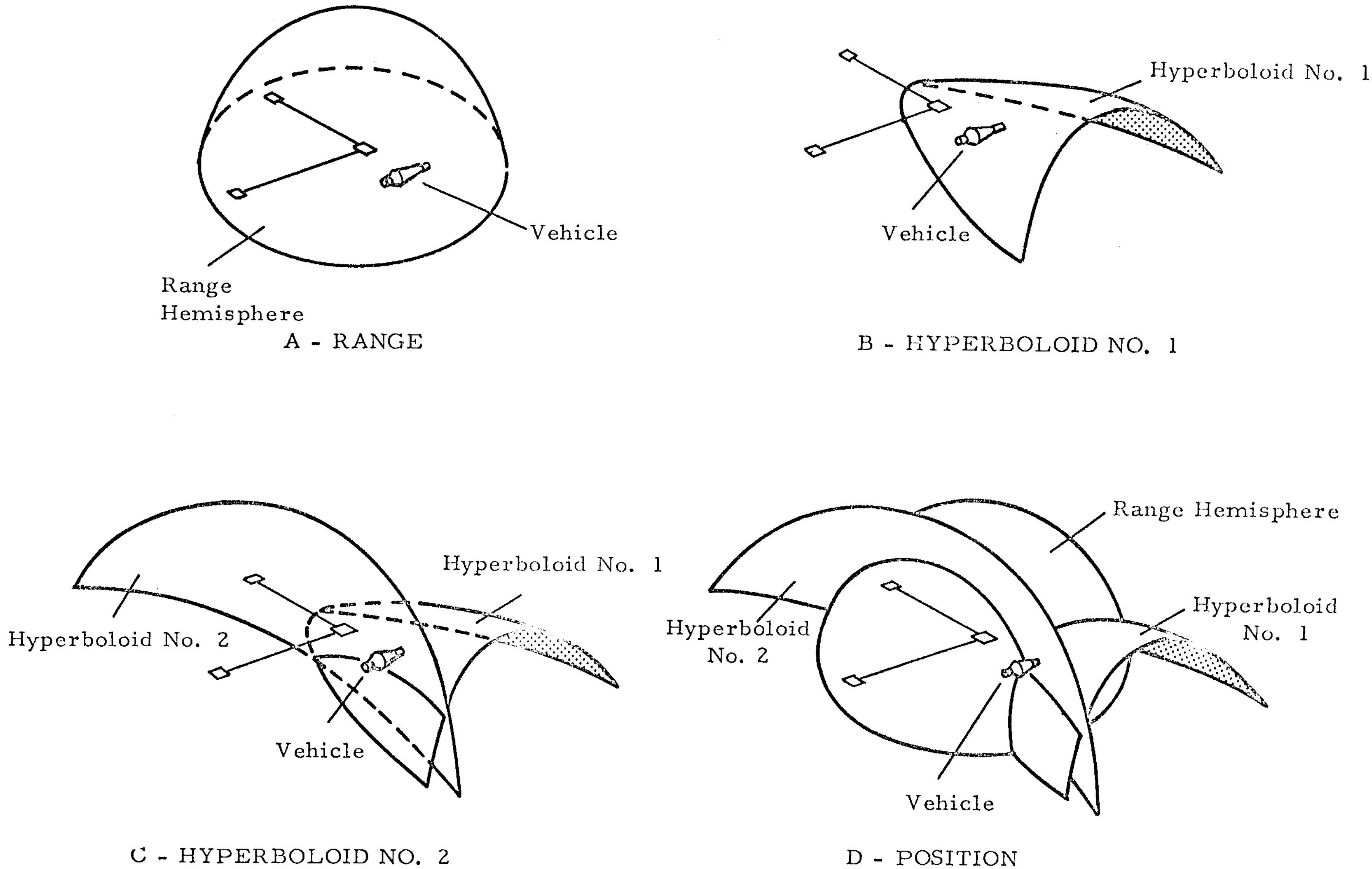


Figure 5-5. Illustration of MISTRAM Theory

g. Transponder
h. Transponder Test Set
i. Auxiliary Checkout Kit

The Precision Measuring Subsystem (PMSS) is an X-band c-w radar which utilizes interferometer techniques to measure the position and velocity parameters of the vehicle. It is the core of the MISTRAM system and contains all of the precision equipment required to produce the system output data.

The Airborne Transponder Subsystem (A/BTSS) (Figure 5-6) consists of a transponder and a filter box aboard the vehicle. The airborne transponder receives, amplifies, frequency offsets, and retransmits the two c-w X-band signals from the central station with a very low uncertainty in the phase shift between the received and transmitted frequency. A specially designed test set for checkout and calibration supplements this subsystem.

The missile penalty imposed by the system transponder has been held to about 15 to 17 pounds, and approximately 100 watts of input power. These figures, especially the input power, will be substantially improved under a proposed redesign study using a voltage-tunable magnetron.

The Acquisition and Tracking Subsystem (ATSS) acquires the transponder and automatically tracks the incoming signal in azimuth, elevation, and polarization. The ATSS antenna supplies pointing information to the central PMSS antenna and to ACSS. The ATSS antenna is used as the transmitting antenna for the PMSS system, as well as the receiving antenna for ATSS.

The Analog Computer Subsystem (ACSS) directs the pointing of the four remote PMSS receiving antennas. This subsystem converts the ATSS analog pointing data into digital form, and supplies this data to the Data Multiplex Subsystem (DMSS) for serializing and transmission over wire or microwave voice circuits to the remote stations. The pointing data is corrected for parallax at each remote station and converted to analog form to drive the PMSS receiving antennas to the proper pointing positions.

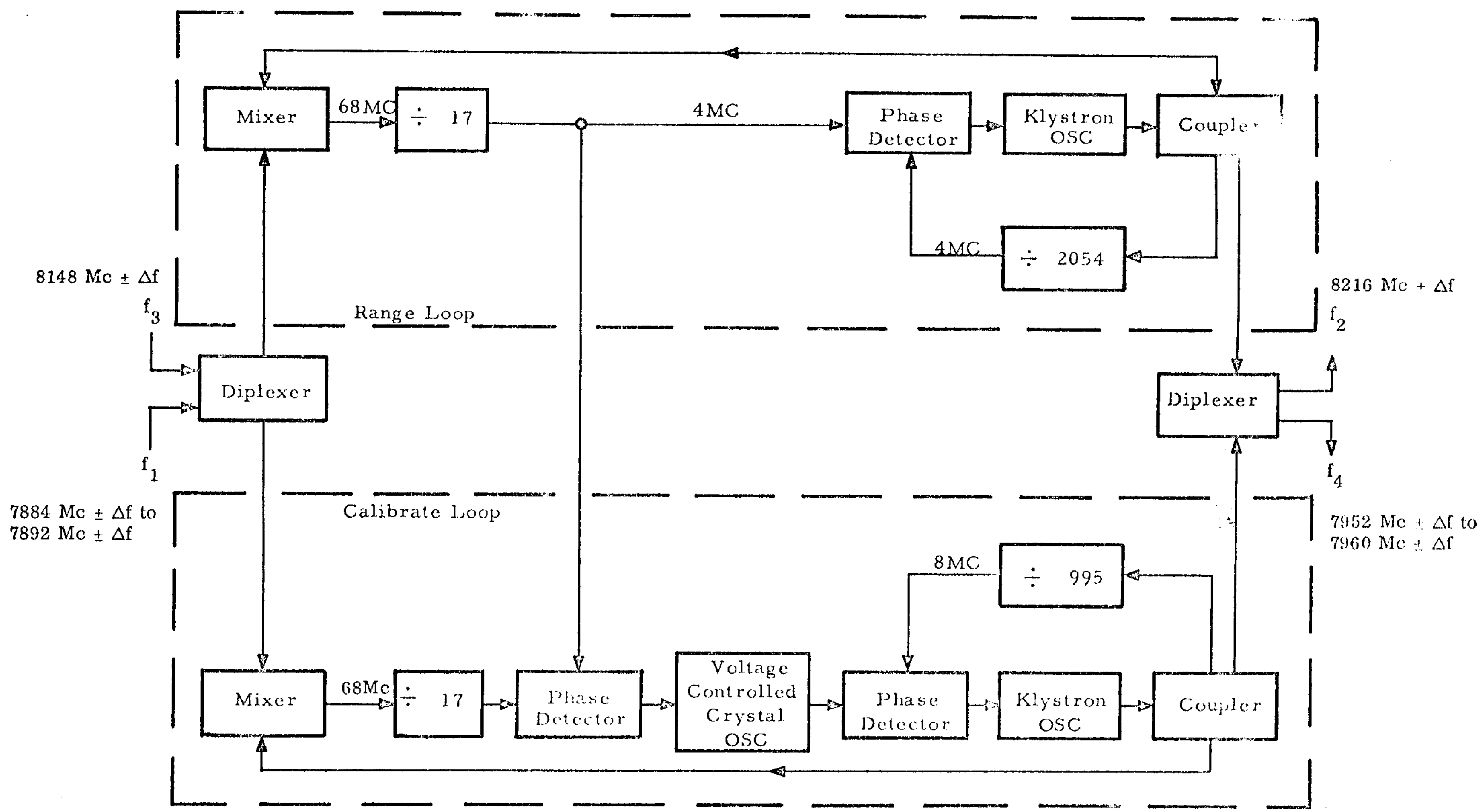


Figure 5-6. Airborne Transponder Subsystem Block Diagram

The Data Transmission/Recording Subsystem (DT/RSS) includes the necessary equipment for the encoding of the primary data words generated by the PMSS, the data words generated by the data multiplex equipment in response to input signals from a refractometer at each station, and the time codes generated in the PMSS into a form suitable for transmission over the RF Communication Link Subsystem (CLSS) to Cape Canaveral. In addition, this subsystem provides for the decoding of these signals in a form suitable for insertion in the 7090 computer in real time and provides a capability for recording these signals for later playback for post-flight data reduction.

The RF Communication Link Subsystem (CLSS) consists of two major groups:

a. Baseline Communication Group - A microwave system which provides the necessary equipment for the handling of all signals between the central station and the 100,000-foot remote stations, with the exception of those signals handled over the coherent link which is part of PMSS.
b. External Communication Group - A microwave link which provides the necessary equipment for the handling of all signals between the central station and Cape Canaveral, including the special DT/RSS signals and the timing synchronization.

The Data Multiplex Subsystem (DMSS) is used for encoding and decoding, in the correct format, various items of data required for transmission between the central station and the 100,000-foot remote stations via the baseline communication link, and for various types of data required for transmission between the central station and the 10,000-foot remote stations via wire lines. The refractometers, which are not actually a part of the Precision Measuring Subsystem from the standpoint of functional procurement, may be regarded as part of the Precision Measuring Subsystem, since they provide the ground index-of-refraction measurements, which, with the Precision Measuring Subsystem output data, constitute the primary data output of the MISTRAM system. These refraction measurements are in real time and will be used to make sample-by-sample corrections in the range and range-difference measurements.

STATION EQUIPMENT (Figure 5-7)

Central Station

The central station equipment includes the ATSS tracking antenna and receiver, the PMSS transmitter and receiving antenna, ten receivers, data-extraction circuits, communication and recording equipment, refractometer, optical tracker, simulator,

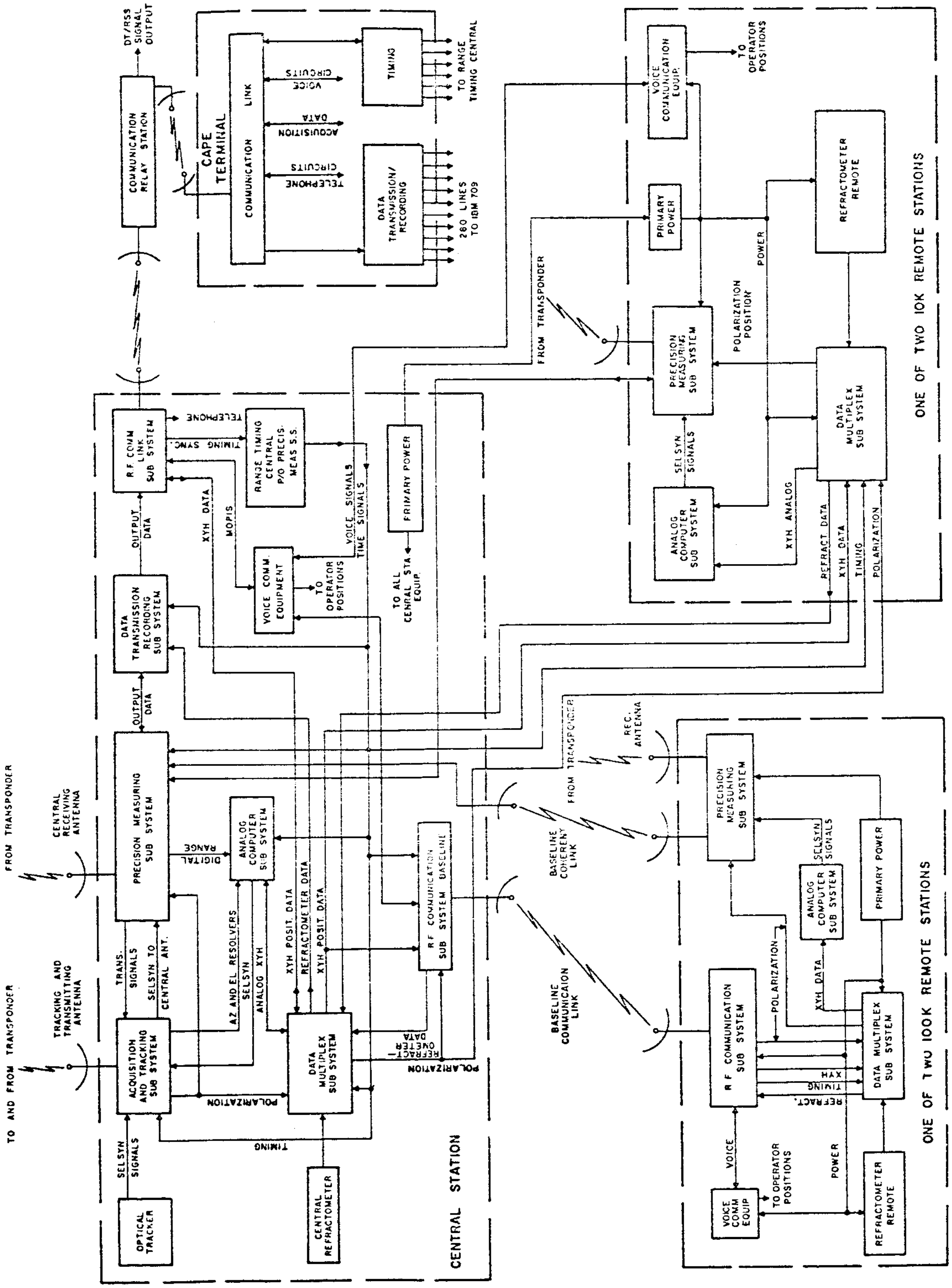


Figure 5-7. MISTRAM Ground Station Block Diagram

and miscellaneous power equipment and normal utilities. Of the ten receivers at the central station, one is used for beacon signals arriving directly from the vehicle, five for return signals arriving via the central station and four remote stations, and four are used for phase-stabilization purposes.

Remote Station

Each remote station houses a simple receiving antenna slaved to the central station PMSS antenna, a receiver for beacon signals, a receiver for phase equipment, power supplies, and normal utilities. The receivers at the remote stations and those at the central station are nearly identical.

Communications between the central station and the four remote stations are accomplished via waveguide over the 10,000-foot baselines and via microwave link over the 100,000-foot baselines. Communication between the central station Cape Canaveral and Patrick Air Force Base will be via microwave relay.

STATION FACILITIES

Size of the facilities required for the system should be mentioned briefly. At the central site, there is a central operations building of about 7000 square feet, including stock room, shop, office air-conditioning equipment room, power control room, and rest rooms, as well as MISTRAM equipment areas. In addition, there is a communication building of about 900 square feet for the central station. Communication Link Subsystem equipment, a 150-foot tower for various fixed antennas and the central refractometer sensing element, and a diesel-generator shelter. At each 10K site, there is an operations building of about 700 square feet and a 100-foot tower for the refractometer. The 100K sites have a similar building and a small communications building, a generator shelter, and a 150-foot tower.

SYSTEM PERFORMANCE

Because evaluations of actual performance are not yet available, the following equipment performance estimates are based on the analog simulations and laboratory tests on subsystems and components.

Random Error		
Range	(R)	0.0300 ft
Range difference	(P and Q)	0.0500 ft
Range rate	($\dot{R}$)	0.0160 ft/sec
Range-difference rates	($\dot{P}$ and $\dot{Q}$)	0.0021 ft/sec
Bias Error		
Range	(R)	0.0280 ft
Range difference	(P and Q)	0.1000 ft
Range rate	($\dot{R}$)	0.0020 ft/sec
Range-difference rates	($\dot{P}$ and $\dot{Q}$)	0.0003 ft/sec

These are rms errors, including median of propagation effects, with smoothing times of one-half second at a data rate of 20 points per second, but excluding the uncertainties of the free-space velocity of light.

These accuracies are obtained with range velocities of zero to 50,000 feet per second, range accelerations of zero to 750 feet per second per second, and range-difference velocities of zero to 3000 feet per second. Coverage at these accuracies is 360 degrees in azimuth and 30 to 600 miles in range at elevation angles between five and eighty-five degrees from any one antenna. With reduced accuracies, this coverage can be increased to a minimum elevation angle of zero degrees with ranges considerably in excess of 1000 miles (essentially hemispheric coverage).

SYSTEM LOCATIONS

Valkaria Site (Ref: Survey Data)

	Location		Height (ft above MSL)
Central Site	27.95625°N	80.55860°W	48.00

	P Baseline	Q Baseline
Az (deg)	167.16	248.82
El (deg)	-0.14	-0.13
Length (ft)	99,676.0	103,616.0

Eleuthera Site

	Location		Height (feet)
Central Site	25.25917°N	76.31083°W	115.0

	P Baseline	Q Baseline
Az (deg)	138.93	183.51
El (deg)	-0.14	-0.25
Length (ft)	88,728.0	156,560.0

CHECKOUT AT LAUNCH OPERATIONS CENTER

The MISTRAM transponder is completely checked on the bench at MSFC prior to installation in the vehicle. After installation present plans call for the vehicle to be checked using the transponder test set. This will be done open loop, if possible.

Upon arrival at LOC the transponder will be again checked, using the transponder test set.

An auxiliary checkout set has been installed at Cape Canaveral and is operated by the range contractor. With this set it is possible to exercise the transponder using an air link, thus simulating open loop radiation. It is not possible to interrogate the transponder with the MISTRAM ground system because of distance between the launch site and the MISTRAM ground complex at Valkaria, Florida.

TELEVISION SYSTEM

TECHNICAL DESCRIPTION

Starting with SA-5, a television system will be incorporated in the Saturn program to provide real time and permanent visual data on the performance of any portion(s) of the vehicle. The video information will be transmitted to the ground by an L-Band FM transmitter. There may be as many as four separate cameras, switched in sequence to provide data on different observation points. Synchronization of the system will be provided by a master synchronizer for camera control. The camera control unit will supply camera scanning signals and video signal amplification. The on-board equipment will be self-contained, requiring only a standard 28 vdc input from the vehicle. A block diagram of the airborne equipment is shown in Figure 5-8.

The ground equipment, shown in Figure 5-9, will consist of a parametric amplifier to provide a low noise figure, a broadband receiver to amplify the input signal and convert it to a video signal, and signal processing equipment.

The signal processing and distributing amplifier removes any noise components from the received signal and holds the level constant.

The sequence decoder receives the signal from the signal processing and distributing amplifier and separates the pictures into the proper number of outputs according to the number of cameras used in the flight system. The signals necessary to keep the pictures from each camera going to the proper output are supplied by the mixer in the flight system and removed here in the sequence decoder.

A special type of storage tube with continuous readout is used for each camera channel to provide continuous viewing on conventional monitors.

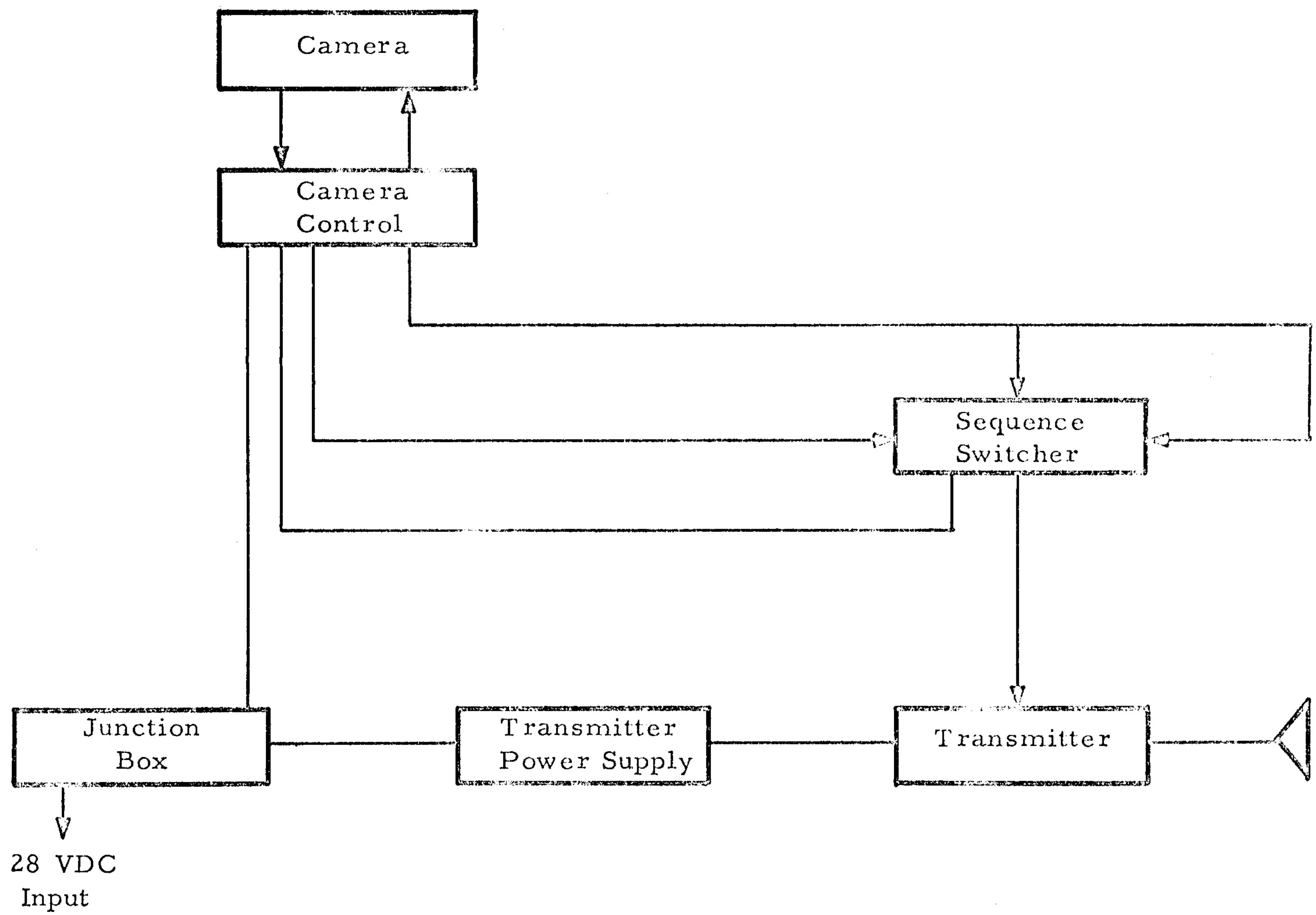


Figure 5-8. SA-5 TV System Schematic

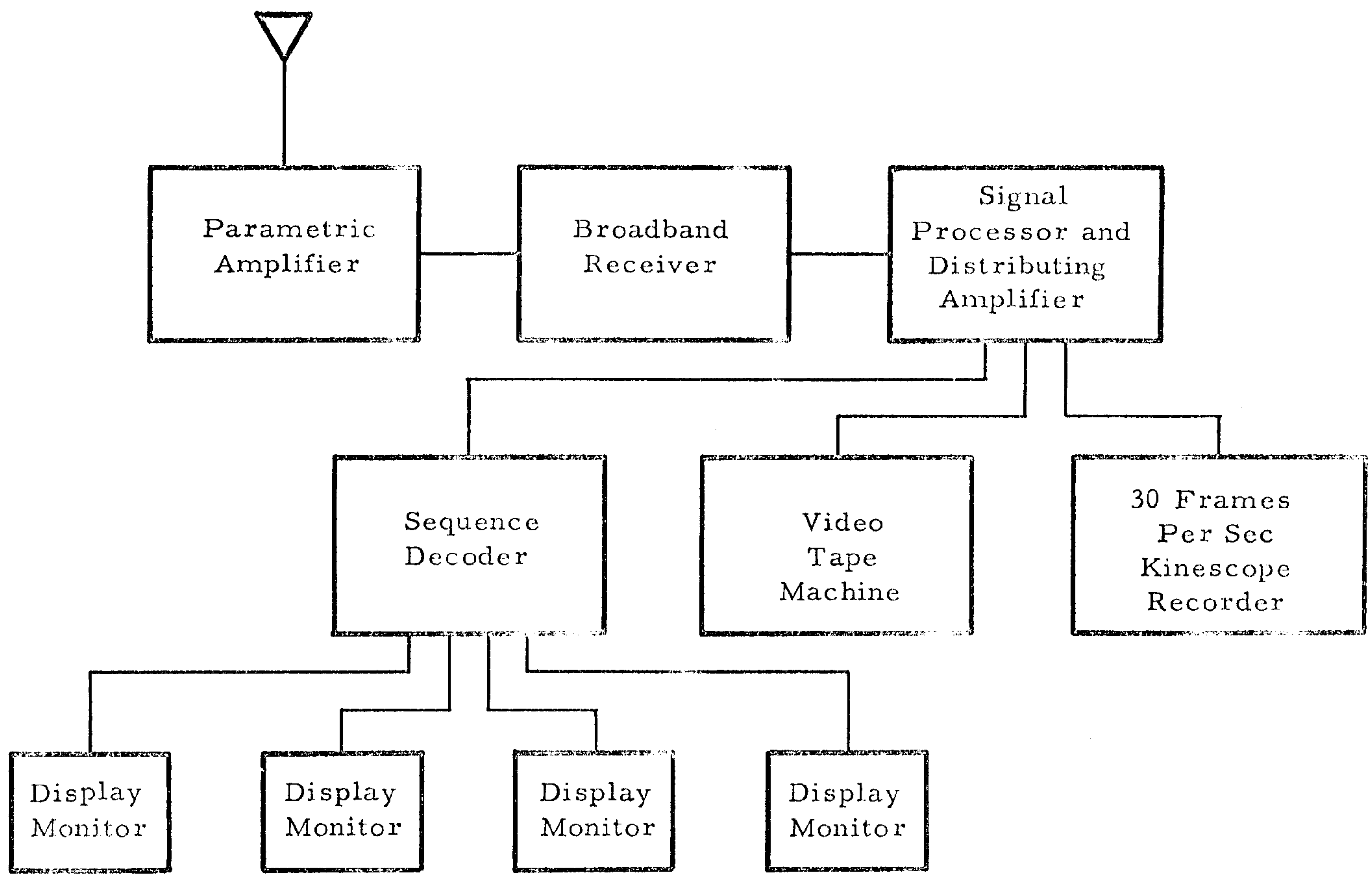


Figure 5-9. Saturn Flight TV Ground Station

A video tape recorder is used to record the complex signal of the multiple cameras coming from the receiver by way of the distributing amplifier. This recording contains all information necessary to feed into the sequence decoder and reproduce the real time pictures. Its output may also be fed to the kinescope recorder.

A special storage display tube is used with special frame code numbering applied on the video tape to provide automatic selection and storage of any one frame of any camera. This picture will be the same quality as that provided by the video tape and may be copied by a Polaroid camera to provide a print in 10 seconds for analysis. The number accompanying the picture is displayed and used to recall the same frame as often as desired for future study.

A kinescope recorder is used to make 16-mm movies of the intermixed camera outputs as a back up for the tape recording. The 16-mm camera makes one picture for each picture from each TV camera (30 pictures per second). Each picture contains numbers to indicate camera number and range time to the nearest second. These pictures are used to make single frame enlargements for study purposes.

The ground receiving station is housed in a 35-foot mobile van, air conditioned and humidity controlled. Complete maintenance and repair facilities are provided in the van for ground and flight equipment.

DESIGN SPECIFICATIONS OF TELEVISION FLIGHT SYSTEM FOR SATURN BOOSTER

Transmitter

Video bandwidth	8 Mc
Modulation	FM
Deviation	16 Mc (for composite video)
Output power	5 watts
Unmodulated frequency	860 Mc ± 0.20 percent
Video resolution (horizontal) of received picture	600 lines

Closed Circuit Camera System

Camera light sensitivity	1.0 foot candle
Video bandwidth	8 Mc

Video resolution (horizontal)	600 lines
Horizontal sweep frequency	15,750 cps
Frame rate	30 per second
Scanning	2:1 interlace

Specifications of TV Ground Station

Specifications of the television ground station for support of the Saturn television system are listed below.

a. Parametric Amplifier

Gain	20 db
Noise figure	1.35 db
Frequency range	860-880 Mc

b. Receiver

Frequency range	860-880 Mc
Gain	90 db
Noise figures	12 db
Intermediate frequency	44 Mc
IF bandwidth	17 Mc
Video output	1 volt p/p composite, sync negative

c. Signal Processing and Distributing Amplifier

Video bandwidth	8 Mc
Output levels	2 volts maximum - composite
Number of outputs	3

d. Sequence Decoder

Video bandwidth each output	8 Mc
Output levels	2 volts maximum - composite
Number of outputs selectable	1 to 16
Switching time	0.1 microsecond
Isolation between inputs	55 db

e. Video Tape Recorder

Video bandwidth	5.5 Mc
Tape speed	15 inches/sec
Recording time	96 minutes

Video input	0.5 to 1.4 v peak to peak with black negative and input terminated in 75 ohms ±1 percent, unbalanced
Video output	0.5 to 1.4 v peak to peak at 75 ohms ±1 percent

f. Kinescope Recorder

Camera frame rate	30 frames/sec
Kine-monitor tube	White face, type P-4 phosphor
Film capacity	1200 feet

g. Viewing Monitor

Video bandwidth	8 Mc
Video resolution (horizontal)	600 lines
Video input	1.4 v peak to peak composite black negative and input terminated in 75 ohms ±1 percent, unbalanced

DIGITAL DATA ACQUISITION SYSTEM (DDAS)

GENERAL DISCUSSION

The DDAS is a digital telemetry system designed for "on-board" data acquisition, transmission, and subsequent processing by ground equipment for presentation and evaluation. This system will be utilized in both the C-1 and C-5 vehicles. Present estimates are that the seventh vehicle in the C-1 series will have a DDAS system on board.

Before launching into a discussion of what comprises a DDAS system, some of the reasons why such a system was designed will be set forth. An automatic checkout system should provide accurate and current data on vehicle status. The method frequently proposed for this requirement includes hardwire connections from each data point to a ground sampling and digitizing system. In the Saturn vehicle system, a number of problems arise using such approach:

- The number of connections from vehicle to ground become exceedingly high.
- Electrical ground loops, noise pickup, connector contact resistances and potentials, line capacitance, etc. affect the accuracy of analog data over hardlines, especially when the lines are long and the signals are low level.
- The addition of hardlines from the vehicle to the ground necessitates their removal at lift-off; therefore, the removal of these parallel lines from a calibrated telemetry system may affect the calibration of the system.
- Accurate data sampling is very difficult to achieve when a long line separates the transducer and the multiplexer. Line unbalance becomes a severe problem.

In considering the above problems, it became clear that a digital system for handling data would be a desirable approach to the problem. If data can be changed into digital form as close to the source as possible, there is less chance for error.

Also, digital telemetry techniques provide a more reliable error-free transmission medium than other techniques, including analog transmission over hardwire. The Saturn telemetry system consists of a combination of three basic telemetry techniques to provide the required transmission capacity and characteristics. These systems are PAM/FM/FM, SS/FM, and PCM/FM. In their approach to an automatic checkout system for the Saturn vehicle, the problems were considered that must be faced if the existing telemetry systems were to be adapted to automatic checkout. The following questions were carefully analyzed:

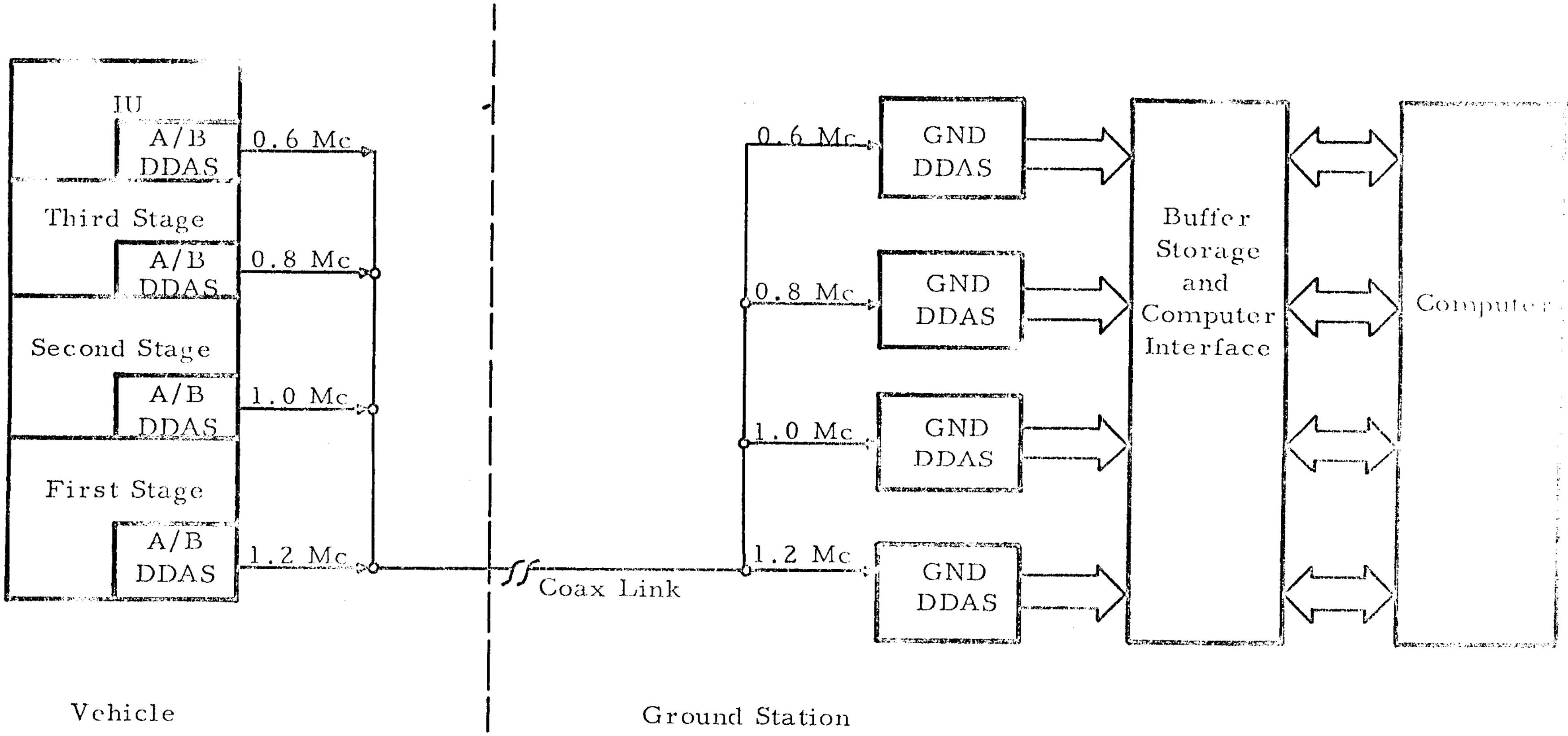
- Could the existing telemetry system be readily modified to provide an output in a form suitable for real-time computer entry?
- Could the telemetry system be adapted to prelaunch data use without decreasing its capability for flight telemetering?
- Could telemetry equipment planned for Saturn serve as a utility link during many hours of prelaunch testing without deteriorating its capability after lift-off?
- Could the resulting data acquisition system provide self-checking features?
- Could the resulting system provide means for checking the instrumentation and telemetry as well as other vehicle systems?

Each of these questions was carefully considered and design modifications of the vehicle telemetry system were evolved which provided an affirmative answer to each of the questions.

In Figure 5-10 is shown a general block diagram of how an airborne and ground DDAS could be employed at a launch site. The inputs to the airborne DDAS boxes consist of PAM multiplexer signals, analog signals that normally go to subcarrier oscillators, and digital signals. The airborne DDAS converts these signals to a pulse code and modulates an oscillator in the range of 0.5 to 1.5 Mc. In the block diagram, four signals are multiplexed onto a coax cable and sent to the ground station. The frequencies were selected merely for illustration. At the ground station, four receivers are tuned to the appropriate frequency and each signal would be amplified, demodulated, and demultiplexed. The information would then be available in a buffer storage where the computer would handle it on a programmed basis.

AIRBORNE DDAS

The airborne DDAS system is essentially a PCM telemetry system as shown in Figure 5-11. The scanning switch is a multiplexer similar to the other multiplexers and is controlled by the clock. It scans PAM data and analog data that normally connect to subcarrier oscillators. To use a mechanical analogy, the scanning switch commutator looks at a particular channel for a fraction of a second. The voltage value that it sees is temporarily held on a storage capacitor by a sample and hold circuit, and then the programmer reads this value into the analog-to-digital converter. Here the voltage amplitude is converted to a ten-bit digital code and read into a digital miltiplexer in parallel. The digital multiplexer is simply a storage register where binary coded words, digital words, and frame sync digits can be brought together in the proper



A/B = Airborne
DDAS = Digital Data Acquisition System

Figure 5-10. Launch Site Configuration of DDAS

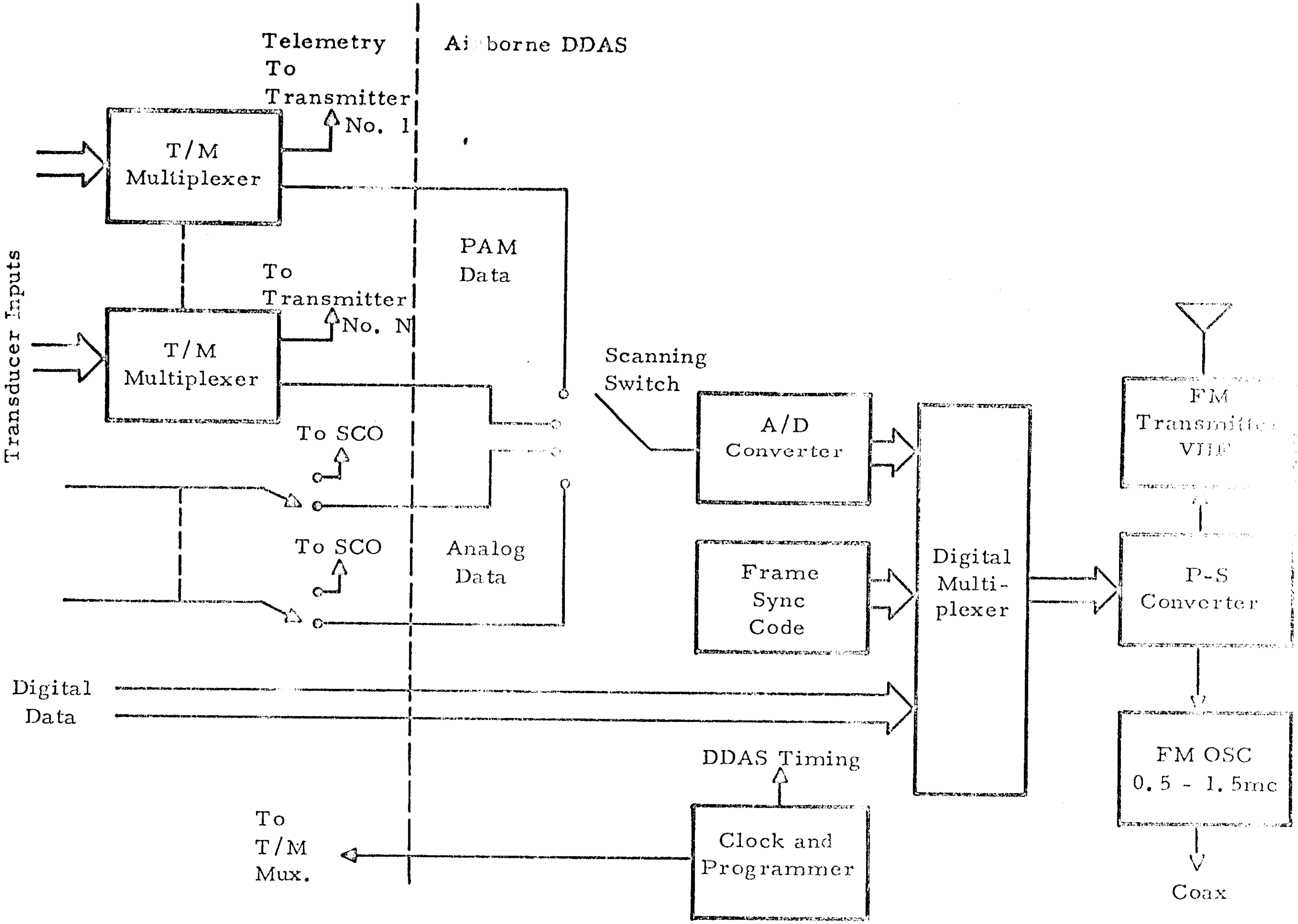


Figure 5-11. Airborne DDAS Block Diagram

format. Upon a command from the programmer, 10 bits of parallel data are fed into the parallel-to-serial (P-S) converter and applied as non-return-to-zero digital data to an FM oscillator. The output of this oscillator will be PCM/FM in the range from 0.5 to 1.5 Mc. The signal is carried by coax to the ground DDAS. An alternate output path will be from the P-S converter to the VHF transmitter offering an RF link to the ground DDAS in cases of longer distances to be covered.

Some of the essential features of the DDAS which are being incorporated into the design are as follows:

- Analog measurements required for vehicle readiness determination and also for inflight telemetry must be presented to the multiplexer with no special connections required.
- Analog measurements required for vehicle readiness determination, but not normally telemetered in flight, must be connected to existing multiplexer channels and sampled at rates appropriate to the expected prelaunch dynamic character of the measurement.
- All subcarrier measurements must be sampled at rates appropriate to the prelaunch dynamic characteristics of the measurements (most of these are static during prelaunch).
- A high capacity multiplexer (30 x 120) and submultiplexer (10 x 12) are being developed. These multiplexers have basic channel sampling rates of 120 samples per second (sps) and 12 sps. With the DDAS, 40 sps and 4 sps are also used.

Scanning of multiplexers is programmed so that only each third frame is accepted from certain multiplexers, thus reducing the channel sampling rate of these channels in the DDAS output to 40 and 4 sps. At least one multiplexer in each stage will be digitized and its output provided to the ground DDAS without reduced sampling rate. This provides channels with sampling rates up to 120 per second for specific measurements with dynamic characteristics.

The general characteristics of the DDAS format from each stage telemetry system are as follows:

Word rate	- 7200/second
Bits/word	- 10
Bits/second	- 72,000
Words/frame	- 60

- Frames/subframe - 30
- Frame identification - 20 bits/frame
- Subframe identification - frame is complemented each 30 frames.

No word sync, parity bit, or word separation bits are utilized. Two reference channels from each multiplexer are digitized and transmitted through the system as continuous check on DDAS operation.

Primary power can be applied only to those portions of the vehicle telemetry which work through the DDAS during stage checkout. In this way, operating time on transmitters can be kept to a minimum during checkout phases when trouble is encountered. The DDAS may then serve as a utility link at any time data is required from the stage.

In Figure 5-12 is shown how the RF link associated with the DDAS can provide a degree of redundancy in the inflight telemetry transmission, as well as means of accurately calibrating the instrumentation system inflight. Redundancy can be demonstrated by the top part of the figure. A transducer signal is applied to a signal conditioning module called a universal measuring adaptor (UMA). The signal is amplified and sent to the multiplexer where it gets sampled. From here the signal becomes PCM/FM through the DDAS link and PAM/FM/FM through the telemetry link. Each of these RF links carries the same information, hence the redundancy.

In the bottom of the figure, the signal flow through the UMA is the same as above. Normally, the signal is applied to one of the subcarrier oscillators between channels 2 through 14. The path to the DDAS is open as shown. When switched into the calibration mode, the SCO is calibrated by a precise voltage through the telemetry link and the UMA can be checked through the DDAS RF link.

GROUND DDAS

A block diagram of the ground DDAS system is shown in Figure 5-13. At the left in the block labeled "source selection" any one of a number of signals can be selected for processing. A signal may come in on coaxial cable from the airborne DDAS around a carrier frequency of 1.2 Mc, for example. If the airborne DDAS RF link were used, the signal would first pass through a telemetry receiver and then would be channeled to the source selection box by coaxial cable. In any event the desired signal is switched into the data processing equipment either manually or on command from the computer. If the signal were transmitted by coaxial cable from the airborne DDAS, it would be

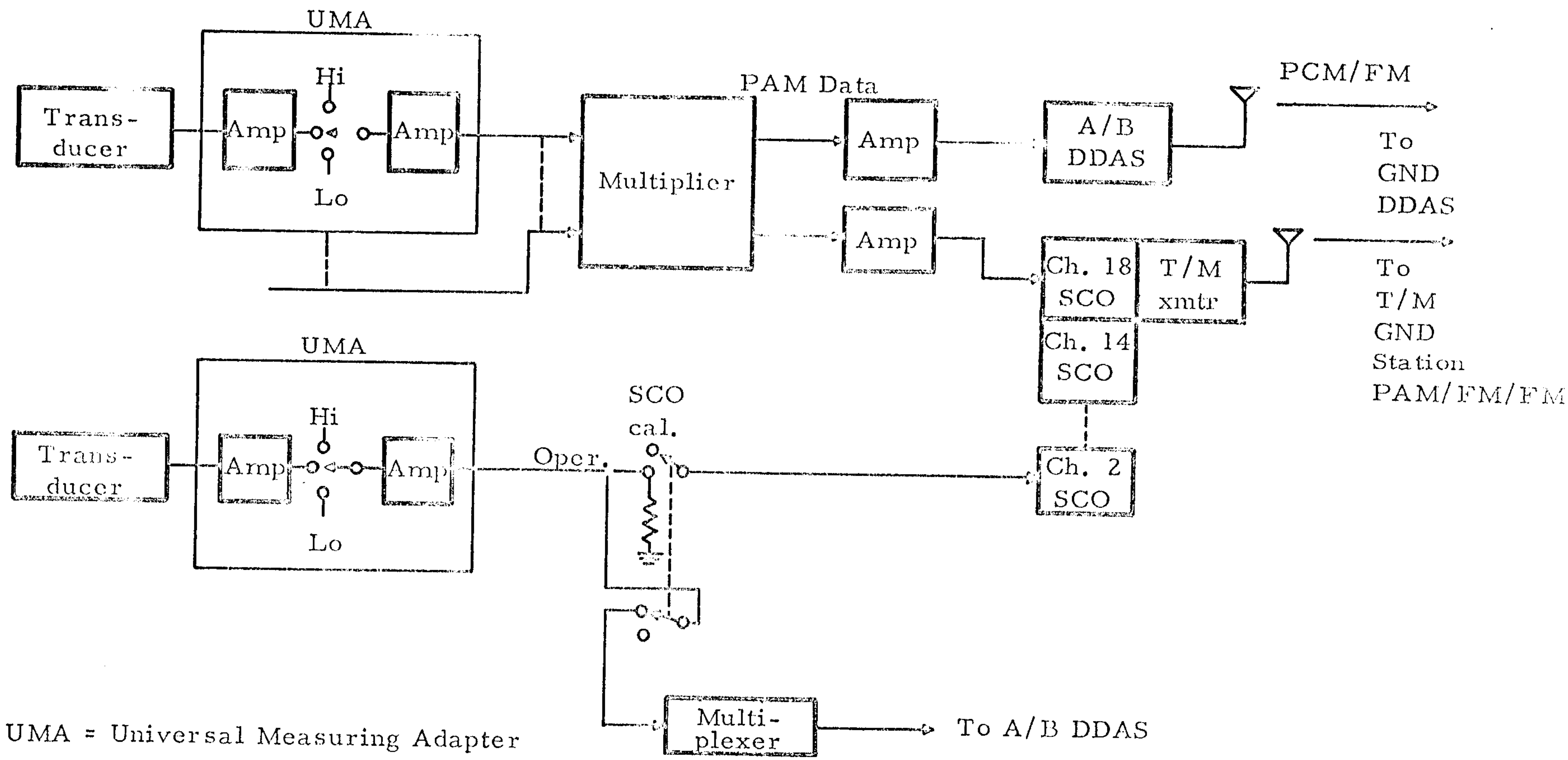


Figure 5-12. In-Flight Calibration Using DDAS

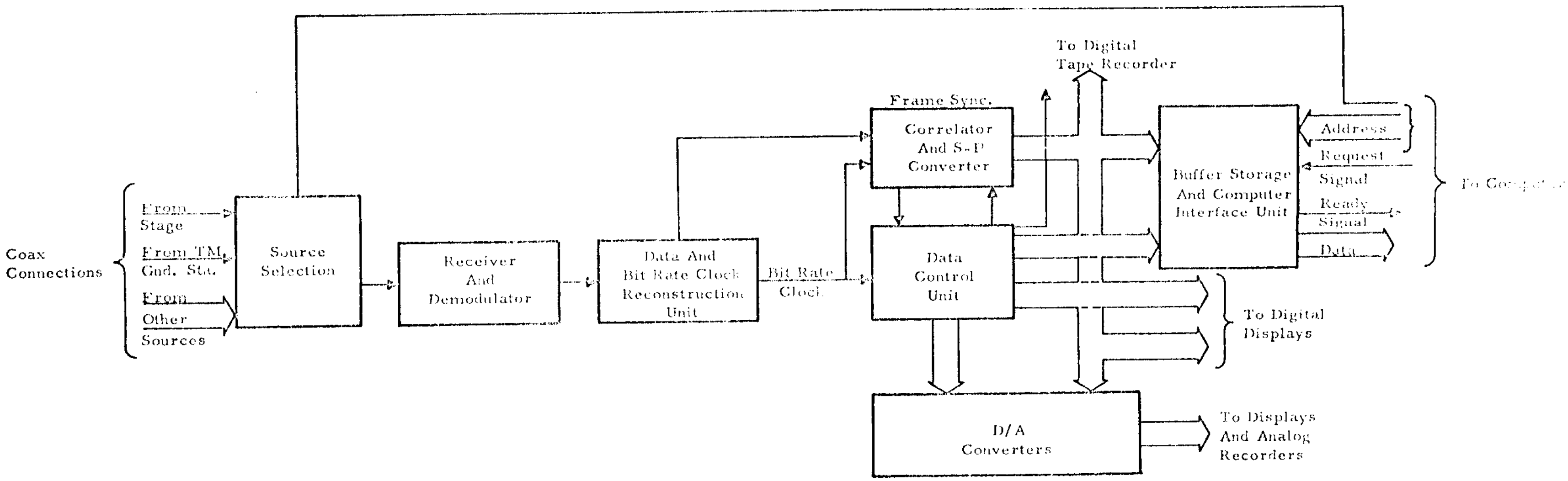


Figure 5-13. Ground DDAS Block Diagram (Stage Checkout Version)

applied to a receiver tuned to 1.2 Mc (example above) and demodulated. If the signal arrived by way of an RF link, it would be demodulated in the telemetry receiver and it would bypass the low-frequency receiver. All data enters the block labeled "data and bit rate clock reconstruction unit" in a serial non-return-to-zero form. Since the signals may have some degree of noise riding through them generated by the transmission process, this unit performs a dual function; it reconstructs the pulse train so that all pulses are noise-free and it establishes the bit rate of the incoming data and produces a clock signal for the remainder of the system. The "correlator and serial-to-parallel converter" contains two digital filters that recognize the two series of binary digits which have been assigned as frame and subframe identification. The registers for the serial-to-parallel conversion are also located here.

The data control unit examines frame and subframe sync patterns from the correlator for periodicity. This is necessary to detect series of data bits that may occasionally resemble the sync pattern but are not it and hence are rejected. The data control unit also contains the logic required to detect an out-of-sync condition and search logic for locating the correct frame sync code. The correct sync pattern controls a group of counters which count in the same sequence as the counters on board the vehicle where the data is being multiplexed, encoded, and placed in its proper format.

With the advent of automatic checkout equipment such as the DDAS and its associated computer program, it must be remembered that the checkout philosophy of the RF and telemetry equipment remains the same. The DDAS system is a redundant unit for the most part, performing many of the same measurements that may later be telemetered during flight. Its primary purpose is to automatize the vehicle checkout. It is only incidental that it will provide a check on the RF and telemetry equipment by providing a comparison with data obtained through the regular telemetry. There are provisions for transmitting this data over longer distances than feasible with a coax link by coupling the data to a UHF FM transmitter. It is thus possible to use the system as a redundant data link during flight to provide a check on the normal telemetry channels. The sampling rate would be decreased with this method, compared to the normal channel information.

SECTION 6

C-5 PLANNING

RF AND TELEMETRY CHECKOUT

Some thought has been given to the philosophy of checkout for the on-board telemetry and RF systems for the Saturn C-5 program. Although no major changes are expected in the types of equipment used, the checkout problem will become more complex by reason of the increase in the number of equipments carried on the vehicle. In addition, the method of launch operations will be changed because of the scope of the program and the vehicle size. The construction of a central instrumentation facility is planned as well as the use of a vertical assembly building for the mating of the various stages to full vehicle configuration. The lack of accessibility to the vehicle on the pad will require a different approach to the sequence of RF and telemetry checkout.

Because LOC personnel are, of necessity, actively concerned with the Saturn C-1 flight test program, the total solution of these problems has by no means been determined. Discussion with LOC has provided an insight into the approach and their feeling for future developments.

The primary location for RF and telemetry checkout will be the vertical assembly building. At this location, all closed-loop tests will be accomplished.

It is expected that the RF equipment checkout methods and procedures will be essentially the same as for the C-1 program. It is not anticipated that any specialized checkout equipment will be required. The use of coaxial and waveguide switches are presently being investigated to permit quick change from closed- to open-loop radiation. The use of antenna couplers is also being considered to permit checkout of the entire system, including antennas, without free air radiation. Because of space restriction on the transporter vehicle, checkout equipment will be held to an absolute minimum. However, it is anticipated that some equipment will be required. An example would be the equipment required for the final check of the digital command system. Since this system is intended to be secure, the use of open radiation might compromise its security. In most cases, however, final checks of the RF system at the launch pad will be made by open radiation to the ground stations.

The telemetry system checkout will also be performed, in greatest part, in the vertical assembly building. Although the stage contractors may have responsibility for the checkout of telemetry equipment prior to mating, it is anticipated that there will be one large telemetry checkout station, since the stage requirements would be identical. The use of DDAS has already been discussed in this report. Although it is primarily a means of checking the measurement sensors and vehicle performance, it should provide a check of telemetry system performance and accuracy by direct-comparison techniques of static measurements. Although the number of telemetry links is expected to increase to approximately 26, the method of checkout should not vary appreciably from present techniques.

As in the case of RF, equipment aboard the transporter will be kept to a minimum. Some equipment may be required in order to troubleshoot equipment failures at the launch pad.

Final system tests will be accomplished by open-loop radiation to primary ground station in the central instrumentation facility.

AUTOMATION

Automation, in itself, is not a panacea for all checkout problems. Properly planned and controlled, it can be a great assistance in verifying performance prior to flight.

In order to properly use automation, the man/machine relationship must be carefully analyzed and the machine used to supplement the capabilities of the man. The machine can accelerate the process of data collection, but the decision-making remains with the man because of his adaptability and a priori knowledge. In addition, there are some checkout processes which can be done faster and better without automation.

FUTURE TELEMETRY AND TRACKING DEVELOPMENT

PCM TELEMETRY

The PCM telemetering system has decided advantages over other systems. The data is easy to obtain and can be more accurate since, with a 10-bit code, the digitizing accuracy is approximately 0.1 percent. There are inherent disadvantages to PCM, however. It is a time division system, allowing no capability for continuous data presentation. This [illegible] on the frequency spectrum, requiring filtering before sampling. This results in a system accuracy degradation, since the filter characteristics will not be known to a degree of precision comparable to the digitizing accuracy. The over-all accuracy depends on the total system and will probably not approach the digitizing accuracy any closer than an order of magnitude.

For certain applications, PCM has advantages and will be used. However, it will not entirely replace the present modulation methods.

UHF TELEMETRY

Since, in the Saturn program, it is the vehicle which is under test and not the instrumentation, only reliable, proven hardware will be used. UHF equipment is, at present, not at the same stage of development as the VHF gear being used. NASA has sponsored the development of UHF solid-state equipment, but it has been less efficient and less reliable than comparable VHF items. In addition, the UHF package is larger than that for VHF.

There is an evaluation program for checking new equipment. This will continue in the search for units with long, reliable life and the ability to absorb more shock with less damage. When tried and proven hardware is available, it will be incorporated in the Saturn program. A complete changeover to UHF for the C-5 vehicle is not now foreseen, however, because of the present and anticipated future development state of this equipment.

TRACKING SYSTEMS

ELECTROMAGNETIC TRACKING

The inherent equipment accuracy of tracking systems has approached the point where the limitation on total system accuracy now lies with our knowledge of atmospheric effects, variations, and physical constants, such as the precise speed of light. It is not envisioned that improvements over the accuracy of Azusa and MISTRAM-type systems can be made until more knowledge of atmospheric propagation and physical constants has been gained.

For those portions of the trajectory beyond the range of land-based equipment, shipborne instrumentation may be required. In such cases, the geodetic position of the ship, the angular and vertical orientation, as well as the pitch, yaw, and roll of the platform must be precisely known if angles are to be measured. If a triangulation technique, utilizing range and range-rate measurements is employed, the linear relationship of the platforms and the angular orientation of the complex as well as the geodetic position of one platform must be accurately known. The range and range-rate approach shows the most promise because it does not require vertical orientation. In addition, accurate radar altimeter data can be used to essentially provide a fictitious earth central range and range-rate station. Until better methods of determining ship position and orientation are available, the accuracy of shipborne instrumentation will not approach that of land-based instrumentation.

OPTICAL TRACKING AND POSITION DETERMINATION

Optical tracking, although still regarded as extremely accurate metric data, has declined in use for space missions for several reasons.

Since the use of theodolites, telescopes, and ballistic cameras is restricted by weather conditions, and since launches must sometimes be made through a "space window," regardless of weather conditions, no reliance is placed on the availability of this data.

The larger boosters present a much greater smoke problem at launch, making optical data coverage difficult. The larger boosters require an increased separation from instrumentation, and, thus, data accuracy is reduced because of poor geometric relationships. Because of these reasons, a Doppler system is being investigated to provide initial position and velocity data at launch.

OPTICAL RADAR

The development of optical radar is being closely monitored. At present, it shows great promise as a new tracking method. If the state-of-the-art advances quickly enough, it might well be used during the C-5 program.